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All communications should be addressed to the Editor.

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Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected in the various grades, as shown, at a Council meeting held on February 17th:—

Associate Fellows.—Comdr. F. L. M. Boothby, R.N., Squadron-Leader J. E. M. Pritchard, Miss J. L. Peatfield, E. H. Mitchell.

Hon. Member.—Mr. C. Alma Baker.

Members.—Flight Lieut. H. Gooch, G. Oliver, R. W. Potts.

Associate Members.—K. Douglas, K. E. Garnett, R. Graham, A. G. E. Joyce, T. W. P. L. Mullings, L. G. S. Reynolds.

Students.—H. G. Brown, R. H. Walmsley.

Associate Fellowship.

The Council have decided to institute forthwith the procedure, which was postponed during the war, of requiring future candidates for Associate Fellowship to pass a qualifying examination in the science of aeronautics, or to produce evidence of having passed some equivalent examination recognised by the Council. A committee is being appointed to make the necessary arrangements for setting up the requisite machinery on the lines of other technical bodies. In this connection it may be interesting to recall the order of foundation of the various technical institutions, of which a list is therefore appended:—

Institution of Civil Engineers (1818), Institution of Mechanical Engineers (1847), Society of Engineers (1854), Royal Aëronautical Society (1866), Iron and Steel Institute (1869), Institute of Electrical Engineers (1871), Institution of Mining Engineers (1889), Institution of Mining and Metallurgy (1892), Institution of Automobile Engineers (1907), Institute of Metals (1908).

Lecture.

Major-General Sir W. S. Brancker will read a paper on Wednesday evening, April 14th, the subject of which will be announced later. Major G. C. Tyron, Under-Secretary of State for Air, will preside.

Educational Lectures.

The question of arranging for the delivery of lectures, primarily of a technical nature, preceded, when necessary, by lectures of a more popular nature, in various centres is under consideration. Suggestions from members as to suitable centres will be welcomed.

Annual Reports and Journal.

The following numbers of the early "Annual Reports" of the Society and of the Journal are missing from those available for sale. The Secretary would be glad to hear from any members who may have copies of these for disposal. Annual Reports for the years 1866, 1867, 1874, 1877, 1883, 1884. AËRONAUTICAL JOURNAL for October, November, December, 1918, and January, 1919.

The Council desire to acknowledge with thanks the presentation to the library of "Air Supply to Boiler Rooms of Modern Ships of War," from Mr. R. W. Allen, and an account of the early experimental work of Laurence Hargrave from Mr. C. Alma Baker; also of a set of lantern slides from Messrs. Vickers.

Members are reminded that the library is open on Saturdays from 2-5 p.m.

In connection with the Annual General Meeting, it is desired to remind members that all Fellows and Associate Fellows and Members are entitled to vote.

Arrangements for the Month.

March 3rd.—Lecture by Professor B. Melvill Jones, Associate Fellow, on "Flying Over Clouds in Relation to Commercial Aeronautics." Lieut.-Col. H. T. Tizard in the chair.
March 16th.—Council Meeting, 5 p.m.
March 17th.—Publications Committee Meeting, 5 p.m.
March 17th.—Lecture by Major C. F. Abell, O.B.E., Associate Fellow, on "Airship Machinery, Past Experience and Future Requirements."
March 30th.—Annual General Meeting, 5 p.m.

W. LOCKWOOD MARSH, *Secretary.*

Dr. Thurston's Lecture.

The Steel Wing Company have called the Editor's attention to the fact that in the report of Captain Thurston's lecture on Steel Construction, published in the September issue of the Journal, there is a statement reported to have been made by Dr. Thurston (page 518) which might give the impression that the reason Dr. Thurston had not mentioned the Steel Wing Company's work in his lecture was that he was unable to secure their permission to do so. The Steel Wing Company wish to point out that the statement in question was not made by Dr. Thurston at his lecture. The Steel Wing Company were far from unwilling to have their work mentioned, and they have shown the Secretary correspondence which shows that they were not unwilling to give Dr. Thurston information. The Steel Wing Company also take exception to Dr. Thurston's suggestion that the Steel Wing Company's improvements were made on suggestions made by Dr. Thurston or any of his colleagues in the Technical Department.

Dr. Thurston is at present abroad, and it has not been possible to communicate with him.—(EDITOR.)

CORRESPONDENCE.

THE ROYAL AIR FORCE MEMORIAL FUND APPEAL.

To the Editor of the AERONAUTICAL JOURNAL.

SIR,—We should be very glad if you would afford us the hospitality of your columns to make an appeal on behalf of the Royal Air Force Memorial Fund.

This Fund has been established to commemorate the services of the Royal Naval Air Service, the Royal Flying Corps, the Australian Flying Corps and the Royal Air Force during the war, by an organisation which will secure such lasting benefits to the officers and men of the Royal Air Force and their dependents as may be worthy of the greatness of the achievements commemorated.

The Executive Committee of the Royal Air Force Memorial Fund, while taking care that their memorials should distinctly commemorate the Royal Air Force, have equally been anxious to avoid mischievous overlapping, and have with that purpose put themselves into communication with the United Services Fund, with Lord Haig's Central Committee and with the Flying Services Fund.

The objects the Executive Committee have decided to pursue are :—

The erection of a commemorative monument to the fame of the Royal Naval Air Service, the Royal Flying Corps, and the Royal Air Force, including the officers and men who joined the Force from Canada, New Zealand, South Africa, and the other overseas Dominions.

The establistment of places of residential education (like Trafalgar Homes) for the children of airmen.

The provision of bursaries available at approved schools.

Generally the provision of such treatment and the rendering of such assistance, as means may permit either directly or in co-operation with other organisations, to officers and men and their dependents who may be disabled, sick, or otherwise infirm.

All officers and men of the Flying Services, whether from the Dominions or from the United Kingdom, will of course be eligible for these benefits.

These objects will be furthered by the Royal Air Force Memorial Fund in the closest co-operation with the United Services Fund and with Lord Haig's Committee in accordance with the requirements of each particular object, so as to prevent overlapping in expenditure; and the Executive Committee are confident that they will both fittingly commemorate the precious national services of the Royal Air Force and realise with due economy the benefits for those whom it is sought to help. An approximate estimate shows that a large sum, probably £400,000, will be required. It is necessary, therefore, to appeal to the abundant generosity of those who honour the memory of the services and sufferings of the Royal Naval Air Service, Royal Flying Corps, the Australian Flying Corps and the Royal Air Force during the war.

We know that in many hearts the memory of these services glows unforgettable. To some it is intertwined with the agony of bereavement; to some it speaks of happy friendship and pleasant reminiscence; but by all who endured the anxieties and rejoiced in the glory of the Great War, not the least honoured place in the proud and thankful recollection of its chequered days is given to the skill and nerve of the brave men who first made war in the unbounded arena of the air, and to the ingenuity and industry of those who rendered that gallant fighting so fruitful to the cause of victory. To all in whose minds these memories are

enshrined we now appeal; of everyone whose heart quickens with pride or pain when he recalls the warfare in the air we ask that these sentiments of patriotism and of affection shall now be shown in a liberality not unworthy of their high temper, and that he will join with us in raising a lasting memorial, which shall carry down to a remote posterity the shining tradition of the Royal Air Force in the war, of its fine courage and its great renown.

Inquiries, donations and subscriptions should be addressed to the Secretary, Derek McCulloch, Esq., 25, Victoria Street, Westminster, S.W.1.

(Signed) ALBERT.
HUGH CECIL.
HUGH M. TRENCHARD.
J. M. SALMOND.
A. V. VYVYAN.

PROCEEDINGS.

FIFTH MEETING, 55th SESSION.

The Fifth Meeting of the Fifty-fifth Session was held in the Hall of the Royal Society of Arts, London, on Thursday, January 8th, 1920, Brigadier-General R. K. Bagnall Wild (Chairman of the Society) occupying the chair.

The CHAIRMAN said he had much pleasure in asking Squadron Leader (formerly Major) H. E. Wimperis to read his lecture. He was well known to all of those in the Air Force, and he (the Chairman) felt sure the audience would not only be amused, but very much interested, and some of the junior members might go away with the idea that there was more in aeronautics on the technical and engineering side than they had realised before. The Society and aeronautics in general had made rapid strides in a very short time, but there were not too many of them working on the subject and it was up to the younger generation to get busy on the job and push the work—especially the engineering side—a great deal further forward.

Squadron Leader H. E. WIMPERIS then delivered his lecture to juveniles on

HOW AIRMEN FIND THEIR WAY.

In the course of his lecture, he said:—Sometimes it was easy to find the way, but at other times it was extraordinarily difficult, and he would describe certain methods they had for getting over those difficulties; they were not perfect nor were the instruments used perfect, so he hoped that someone there might hit upon improvements arising out of what he was going to say, and, if so, he hoped they would write and tell him all about it.

Suppose we were in the middle of Hampstead Heath on a very dark night and that there were no lamps nor lanterns that one could recognise and we wanted to find our way. One would, of course, suggest that a compass would first be necessary. A night marching compass with a luminous dial was the next step. With these we could find how far one had gone in a certain direction. The pedometer would show how many miles we had walked in any time and a line could be drawn in the direction in which the compass showed we were going and that line could be made long enough to represent the number of miles walked in that direction. So we should know our new position. That was very like the problem before an airman flying in the night or above the clouds. They had the same instrument—the compass—here is one fitted on all scout and other small machines, and here is another designed for big machines. To correspond to the pedometer, to show how far the aeroplane travelled, a little fan, which he showed, could be used, which gave an indication on a dial of the number of miles travelled. Aeroplanes were not usually fitted with that instrument, but with an instrument to indicate the speed and a watch to tell the time, with these one could tell the distance travelled. By means of the compass one could travel say due North and then South-West, and then due East so as to land at home again, and in fact do everything in the air that could be done on the ground, when there was no wind. When the big airship R.34 flew from England to America, a distance of 3,100 miles over the ground, there was a head wind, and she had to fly 4,000 miles through the air. On her return journey she flew 3,300 miles over the ground as she did not land at the station from which she started, but she had a wind behind her so that she only had to fly 2,800 miles independent of the wind. He related a story of two men walking towards the City of Cork, who were repeatedly told that it was seven miles off, one of the men remarking, upon finding a sign-post still indicating seven miles, "Thank heaven we are keeping pace with it." In the air one did not always keep pace with the objective. When

travelling in an airship at 50 miles per hour and opposed by a wind of 60 miles per hour one got further away from "Cork" the nearer one tried to get to it! In the air one did not know, of his own initiative, whether there was any wind, what was its direction nor how fast it was going. If one were in a balloon drifting at 60 miles per hour it would not be realised that there was any wind and a candle flame would not blow one way or the other. In an airship drifting, with the engines shut off, one might be going 20 miles through the air, but over the ground one might have travelled 80 miles or nothing. If the wind were a side wind the airship would be going in a different direction from that in which it was heading. If one imagined the air completely at rest and the earth moving, that gave the same relative motion. The angle between the direction in which one wanted to go and the direction in which one steered to get there was called the angle of drift. He would mention ways in which one could determine one's whereabouts after flying a certain time. There were certain inventions coming forward which were going to be an enormous help for that purpose. There was the wireless telephone by means of which the pilot could be told from the ground where he was near, what the weather was like at different places, the direction of the wind, and how fast it was going. Another thing was the existence of lighthouses. In Rudyard Kipling's story, "With the Night Mail," in "Actions and Reactions," the country is pictured starred all over with aerial lighthouses to light the way of the aircraft coming in from all directions. A picture is given of the South African weekly mail arriving at the Highgate Receiving Towers, and also of the Bombay, Antwerp and Yokohama mails. The scheme had actually been begun by putting up an aerial lighthouse near London. Wireless telegraphy and also astronomical observations were used in direction finding. The lecturer then showed the path on the chart followed by the American flying boat N.C.4, which got right through from America to the Azores and afterwards to Great Britain. While she was at the Azores the British Sopwith machine was waiting in Newfoundland for a chance of flying across, and when Hawker and Grieve heard that the N.C.4 had arrived at the Azores, they decided the following day (Sunday) to start off, but failed in their attempt to fly the whole way to Ireland. The next flight across the Atlantic was that of Sir John Alcock and Sir Arthur Brown on the Vickers-Vimy machine. They made the journey right away from America to Ireland—the first time the direct passage had been made. The next attempt—also a successful one—was that of the big airship R.34, which flew right across to New York and a few days later made the return journey by a more southerly route. The lecturer then read extracts of Mr. Hawker's remarks on his Atlantic flight, in which he said the sky was bright and clear at the start, but after about ten minutes the fog was hanging on the Newfoundland coast. They knew, however, that they would soon leave it behind, and they were soon jogging along at a height of about 10,000 feet with the engine roaring contentedly as though it was not going to misfire until the tanks were dry. By two o'clock the sky had turned all purple and the clouds below became pitchy and they only caught sight of the ocean infrequently. A quarter of an hour later the conditions changed for the worse, the sky became hazy and thick and they perceived that there was some pretty heavy stuff ahead. It was not very solid so they pushed the nose of the machine into it and pushed through. There was not much difficulty in keeping the course. Their altitude, now about 12,000 feet, was over the mass of clouds, and the navigator took observations of the stars. About six o'clock in the morning they were confronted with a bank of black cloud appearing as solid as a range of mountains. Though the machine was at least 15,000 feet high they could not get over them and there was trouble with the engine through the water boiling away. Hawker said he was not altogether without anxiety, though he knew they were on the steamer route, because there was so much fog that they might have passed close to a ship without seeing her, but at last a hull loomed out of the fog and he shouted with joy. Grieve said he felt like doing the same, but evidently the tradition of the Silent Service, to which

he belonged, was too much for his vocal chords. They flew down to the sea and were safely rescued by the good ship "Mary." The Vickers-Vimy which made the direct flight from Newfoundland to Ireland was a two-engine machine and was one of the firm's standard make, just as it had been prepared for war work. It was originally made to carry a crew of three and a ton of bombs. The capacity for carrying military armament was utilised for carrying petrol of which 870 gallons were taken. Sir John Alcock said the time taken in the flight was just under 16 hours and the petrol that remained in the tanks would have taken them another 800 miles. Sir John Alcock said he flew along a route closely approximating to that intended, so that was an example of a famous airman who knew "how to find his way."

The next of the famous air journeys was that of the airship R.34, of which he showed a photograph lent by Colonel Cave-Browne-Cave. She was of 2,000,000 cubic feet capacity. Her flight across the Atlantic took 108 hours and the return journey 75 hours. The next famous journey was that of Sir Ross Smith and Sir Keith Smith from England to Australia. They were to win £10,000 if they succeeded in doing it in 30 days, and they did it in 28. Their course was worked on a chart which he showed and it took them to Paris and Rome, across the Mediterranean to Egypt, Damascus, Bazrah, Karachi, Calcutta, the Straits Settlements, and finally Australia. It was a wonderful flight and full of potentialities for the future. It was more convenient in many ways to fly over the land than over the sea, but it would be best to transfer to new machines at the stopping places. He showed a picture of the machine which flew to Australia. Sir Ross Smith, in his account of the journey, said they flew to Folkestone, across to Boulogne where they ran into a snowstorm. They climbed above it to a height of 3,000 feet, where their thermometer registered 25 degrees of frost. He recognised Roanne and they came down below the clouds and flew across the Saone river and reached Lyons before dark. It was very cold above the clouds. Their breath froze on their face masks and their sandwiches were frozen solid. The next morning they flew to Marseilles. On Wednesday, December 10th, they were up at dawn and at 8.30 the fog lifted and they started across the islands, straight for Australia, flying by compass. They had no wireless, but dropped a message in a bottle, which was picked up, stating that all was well. They landed in Australia at Port Darwin.

What was called dead-reckoning was the basis of all navigation. It was necessary to check it from time to time as one's estimate of the direction of the wind or of its velocity might be wrong. There were two useful methods of checking it. One was direction finding wireless telegraphy and the other observations of the stars. The wireless waves went with the speed of light—186,000 miles a second—but however fast they went, if one had a coil of wire wound on a rectangular frame and turned the frame round so that the current received was the maximum one knew that the receiving coil pointed in the direction of the sending station. When the current was a minimum it was at right angles to the direction of the sending station.

Lieutenant CATT then gave a demonstration of the use of the apparatus.

The LECTURER continuing, said the airmen had their receivers attached to their ears and the noises of the signals were easily heard. Supposing one were flying over the English Channel and a station at Brighton were found by the coil to be due north-east and another, say, at Bournemouth to be north-west, then the exact position of the aeroplane could be found by drawing these two lines till they cut. This is easy to understand as the two stations would tell the airmen what stations they were and they could look up the places on the map and then draw lines at the angles given by the coil. It was well known that astronomers could tell where any star was, or was going to be, at any time. Whilst an airman was flying over the English Channel they could tell him that the sun was, say, vertically over Khartoum or that some star was vertical over

St. Petersburg. Suppose that one were flying over England, but did not know what part, if the astronomical tables showed the star Vega was over Oxford, and this same star was seen to be vertically over the machine it would follow that the machine must be above Oxford, but if Vega were 10 degrees away from the vertical the machine would be 10 degrees on the earth's surface away from Oxford; somewhere on a circle at that distance. To find the position a line had to be drawn for Vega, and by drawing another line for another star it was known that the machine must be at the crossing point. He showed a simple method of finding how far the sun was from the point immediately overhead. By means of a circular board with circles marked with the number of degrees and a projecting peg in the centre and by pointing the peg straight at the sun (represented by the lantern) the end of the shadow of the peg indicated the number of degrees from the vertical. But a man in an aeroplane did not know whether the machine was horizontal or not, and although a machine was on a banked turn—even at right angles to the horizontal position—a glass of liquid held parallel to the floor of the aeroplane would not be spilt! This was due to centrifugal force—an effect of acceleration. (Captain BYGRAVE then demonstrated this phenomenon with a vessel of coloured water, which did not spill although he swung it to every angle from the perpendicular.) When a machine got out of the upright position in a fog the airman did not know it, and thought there was something wrong with the compass. One could only rely on the compass when flying straight, and the fact that one was flying straight was ascertained by means of a gyrostat, which he showed. The pointer on the dial always tried to point in the same direction and when it was tilted it processed on the dial accordingly as one turned to the left or right. The rotation of the gyrostat was caused by the rush of air through the vanes of the wheel.

He then showed amusing pictures giving an idea of prophecies in the past of the development of flying, including Jules Verne's famous "Clipper of the Clouds," which was described as being silent, although it had a hundred propellers, and an idea of the big flying boat was given by Com. Douglas Hallam in a book called "The Spider Web." It contained sleeping, lunch and smoking-rooms. It was 240 feet long, weighed 20 tons and made 200 knots. She had wireless and instruments which showed latitude and longitude without any calculation. Rudyard Kipling pictured great air vessels in the year 2000, but they were not as great as the R.34. They were to go at 240 miles an hour. The other day Lieutenant Powell flew on the London-Paris route at 158 miles an hour. The earth rotates at about 600 miles an hour and if our speed were increased to that limit the sun would appear to stand still and it would always be daylight. Probably Kipling's prophecy in "With the Night Mail" was the best that had been made, but we were going to get "there" quicker than he prophesied.

The lecturer then invited the audience to go with him on an imaginary flight in the air. He showed pictures of various aircraft, including the 15-ton Porte boat of 1,800 h.p., which he said had already been built and flown. Ascents could be made from the gun turret on a battleship and there were ships with flush decks on which landings could be made. He also showed descents by parachutes which could be resorted to if the aircraft were damaged. He also showed some beautiful pictures of clouds viewed from above, and views from the air of London, the Crystal Palace, Southend, Eastbourne, Beachy Head, Newhaven, Brighton, the Isle of Wight, Venice, Salonika, Stamboul, the Golden Horn, and finally Cambridge.

He concluded by expressing his thanks to General Brooke Popham, General Brancker and others for the loan of slides, and also to Captain Bygrave, Lieutenant Catt and others for assistance they had given him.

After the lecture wireless messages from Paris were received by the apparatus in the hall.

On the motion of the CHAIRMAN a hearty vote of thanks was accorded the lecturer.

PROCEEDINGS.

SIXTH MEETING, 55th SESSION.

The Sixth Meeting of the Fifty-fifth Session was held in the Hall of the Royal Society of Arts, London, on Wednesday, January 21st, 1920, Wing-Commander Cave-Browne-Cave presiding.

The CHAIRMAN said he wished to introduce Mr. Cole, who would lecture on "The Principles of Rigid Airship Construction." In order to explain Mr. Cole's connection with airship work and with what good authority he could speak on this subject, he must go back to the early history of British rigid airship construction. Rigid airship No. 1, "Mayfly," was designed and constructed by Messrs. Vickers, at Barrow, but was destroyed in a mooring experiment before she was actually flown. Official enthusiasm for airship construction was then such a delicate child that this blow killed it for many years. Rigid No. 9 was started many years later—also at Barrow—and it was only after the work had been stopped and restarted several times that the ship was completed. Although her completion was much delayed her performance compared very well with that of German ships designed at the same time.

She was followed by ships of 23 Class, also designed by Vickers, and later by 27, 28 and 29, designed mainly by the Admiralty, and of which R.29 especially did some excellent flying. During this time the war had started, and casualties to German airships began to supply useful information. From the first Zeppelin brought down at Revigny we learnt a certain amount. L.15, brought down in the Thames, although not burnt, sank before she could be towed to safety. Our officers reached the ship about ten minutes before the extreme tail sank, but just managed to secure samples of each type of fabric. A Zeppelin was brought down in fairly good condition in the marshes near Salonica, but it was a very long time before details of any value reached home. S.L.11, a wooden ship, which was burnt at Cuffley, was so completely destroyed that the remains fell in a circle not more than about 100 feet diameter. We then received our real gift. L.33 was damaged in a raid on London, but managed to get out to the North Sea. The condition of the ship and the look of the sea did not, however, appear good to her captain, and he turned round and came ashore at Little Wigborough. Having landed, the ship was burnt, but beyond the destruction of the fabric and the collapse of part of the framework very little was destroyed. It was at once decided to take full advantage of this gift, and Mr. Cole and a party of draughtsmen were sent down to live alongside the wreck and trace out and draw every detail of the ship. This was done down to the detail of the very last wire. From this data R.33 and R.34 were built, the similarity of the ships to their German friend being as close as that between their numbers. Subsequent German casualties gave us further information.

In the collection of all this information and in its conversion to use of design, Mr. Cole played the leading part. He had, of course, been also intimately concerned in the design of both the earlier and also the latest ships of British design. He must, therefore, be regarded as an absolutely first class authority on this subject, and, although as in all engineering matters there is considerable divergence of views about many details, they would hear with great interest what he had to say, and he (the Chairman) hoped the contentious points might be discussed, as he saw that other authorities on construction were well represented there.

Mr. A. P. COLE, R.C.N.C., A.M.Inst.N.A., then delivered the following lecture:—

THE PRINCIPLES OF RIGID AIRSHIP CONSTRUCTION.

So far as is known, the only papers containing reference to the principles of rigid airship design or construction are those delivered by Herr Dornier to the German "Schiffbantechnischen Gessellschaft" in 1915 and by Mr. C. I. R. Campbell before the Institute of Naval Architects in 1919. The former paper dealt particularly with the Zeppelin, but while it contains valuable information yet it does not deal with the fundamental principles underlying rigid airship construction.

Further, the figures and estimates that are deduced are based on performances of the earlier Zeppelins and have been substantially improved upon during the war. The present paper is intended to state as far as possible the various principles underlying the design of a rigid airship, in the hope that such information may be of value in the progress of this important branch of aeronautics.

It is essential before considering the details of airship construction, to have some knowledge of the terms which are used, for instance, in specifying performances. These terms, while perhaps more or less familiar, are nevertheless very loosely applied, and it is very desirable that they should be defined with some degree of exactitude.

Explanation of Terms.

The *total lift* of a rigid airship is the buoyancy at ground level with all gasbags full and an excess pressure of gas of 5 m.m. water above the atmosphere at the bottom of each bag, the ship being statically at rest and in equilibrium. The total lift is measured by the product of the volume of the gasbags in this condition and the difference between the air and gas densities. If hydrogen is used, the difference between the air and gas densities is arbitrarily taken, for the purpose of comparison between different ships, as

.068lbs. per cubic foot capacity
or
1.09 kilograms per cubic metre capacity.

This figure is slightly lower than the average usually obtained in practice, so that specified airship performances are usually underestimated.

If helium is used, the standard lift is taken as

.0629lbs. per cubic foot
or
1.00 kilograms per cubic metre.

The *fixed weights* of an airship include all items that are necessarily carried in flight, but which cannot be moved so as to affect the trim or heel of the ship. They may be sub-divided into :—

1. Hull or structural weights.
2. Fabric weights.
3. Car and machinery weights.
4. Miscellaneous weights.

Hull weights include all structural items such as longitudinals, transverses, castings, fins and planes, structure excluding the fabric covering, diagonal, net and chord wiring, fin inter-bracing wires and any other wires necessary for structural strength, the keel or corridor, structure at mooring point, etc.

Fabric weights include outer cover, fin, elevator and rudder covers, gasbags, and all cord network.

Car and machinery weights include all gondolas slung away from the ship, together with the suspending wires and struts, machinery, radiators, water and oil tanks.

Miscellaneous weights include all items which cannot be classified under the above heads, such as ventilation trunks, controls and telegraphs, wires and fittings, mooring and handling ropes, fixed petrol tanks, petrol fitting and emptying systems, ballast bag fittings, automatic and manœuvring gas valves, bomb triggers and shutters, electrical equipment and wireless gear.

The *disposable lift* of an airship is the difference between the total lift and fixed weights. With the arbitrary value given above for the total lift, the disposable lift is usually expressed for the purpose of comparison of different ships, as a percentage of the total lift.

The disposable lift is balanced by the *non-dischargeable and dischargeable weights*. The non-dischargeable weights are those items not included in the fixed weights which are necessarily carried in flight, but which cannot be discharged overboard or otherwise consumed for the purpose of attaining the maximum static height. They include crew, passengers, merchandise, landing ballast and emergency fuel, and such stores that it is necessary to land.

The dischargeable weights, which make up the balance, include water or other ballast (ex. landing ballast), petrol and oil (ex. emergency petrol and oil), stores, slip petrol tanks, etc.

The *maximum static height* is the height at which the ship will be statically in equilibrium with all the dischargeable weights discharged. For purposes of comparison between different ships, it is usually calculated on an initial lift of hydrogen gas on the ground of .068lbs. per cubic foot, and in the normal atmosphere for S.E. England given in the Meteorological Glossary, page 54. The maximum static height is usually referred to as the maximum height. Appendix I. gives the maximum static height for various Zeppelin ships. With the ship running ahead it can be exceeded by the use of the elevators. The maximum height so obtained is called the maximum dynamic height.

The *pressure height* is the height at which the ship begins to blow off gas through the automatic valves. At any height below the pressure height the ship can manœuvre without losing gas, but if at any time the ship rises above the pressure height gas will be discharged. The pressure height is then increased to the maximum height to which the ship has gone.

Limiting Factors to Size.

In general, the dimensions of a rigid airship are limited by the size of the building and housing sheds. These limitations are length, overall height, overall width.

It is desirable for handling that there should be at least 10ft. clearance over the top of the ship when the bumping bags are touching the ground. Except when it is necessary to berth two ships in one shed, the limitations of width do not materially affect the dimensions.

It may be mentioned that these limitations are already proving a bar to rapid development in airship design, since the natural tendency for progress and greater efficiency is in the direction of larger ships.

The transverse form of the ship at any section is usually determined from structural considerations, and is generally a polygon with an odd number of sides (17 in R.23, 25 in R.33) which can be contained within a circumscribing

circle. An odd number of sides is preferable so as to have a longitudinal at the top of the ship and a flat side to form the corridor at the bottom.

The profile may be divided into three distinct portions, namely, entrance, parallel body, and run. From model results it appears that the factors most affecting resistance are the values of the three ratios

$$\frac{\text{entrance}}{\text{diameter}} \qquad \frac{\text{parallel body}}{\text{diameter}} \qquad \frac{\text{run}}{\text{diameter}}$$

Values of these factors for different ships are given in Table I.

TABLE I.

Ship.	Entrance / diameter.	Parallel Body / diameter.	Run / diameter.	Length / diameter.
R.23	1.04	7.36	1.70	10.1
R.31	1.81	5.0	2.67	9.48
R.33	2.33	1.875	3.97	8.17
L.71	2.33	3.12	3.97	9.42

Of the first three forms that of R.33 has the lowest coefficient of resistance. L.71 is similar to R.33 with 30 metres added to the parallel body.

The actual shape of the head appears to be of more importance than that of the tail. It is essential in designing these profiles that every discontinuity in the fair lines be avoided as much as possible This is specially true on the head, and also where the head merges into the parallel body; consequently the longitudinal girders forward are generally curved to the profile of the ship rather than built in straight lengths between transverse frames.

For similar ships, the volume of the gasbags (and therefore the total lift) varies practically as the cube of the diameter. Values of the non-dimensional factor—

$$\text{Volume}/(\text{Diameter})^3$$

for various ships are given in Table II.

TABLE II.

Ship.	Vol. of gasbags/(Diameter)^3
R.23	6.63
R.31	5.45
R.33	4.07
L.71	4.96

Stabilising and Controlling Surfaces.

Any elongated body, such as an airship, when moving in still air in the direction of its longest axis, will, if slightly inclined to the direction of motion, experience a moment tending still further to increase the inclination. The motion is therefore unstable, the moment being called the "negative righting moment." The existence of this moment is in general due to a region of positive air pressure over the bow and a corresponding region of negative pressure over the stern, which cause the line of action of the resultant force to be some distance forward of the centre of gravity. The effect of fitting stabilising surfaces at the stern of the ship is to introduce a righting moment caused by the air pressure upon these surfaces. Usually in rigid airships, two vertical planes, one above the ship and one below, are fitted, and two horizontal planes, one on either horizontal diameter. Part of each of the planes is made movable, so as to obtain controllability of the

airship. The movable parts of the horizontal planes are termed elevators, and of the vertical planes, rudders. The total fin area includes the movable planes (Fig. 1).

The mathematical investigation of the stability of an airship when moving in still air either in a rectilinear or curvilinear path is difficult, and dependent for its solution on the elimination of certain of the resistance derivatives from the general equations of motion of a free body. Further the application of any stability criterion based on small disturbances from a uniform path brings into account the virtual masses in various directions of motion and the virtual inertia of the airship, none of which quantities has yet been accurately determined. From model results, also, it appears that the stability criterion varies with the

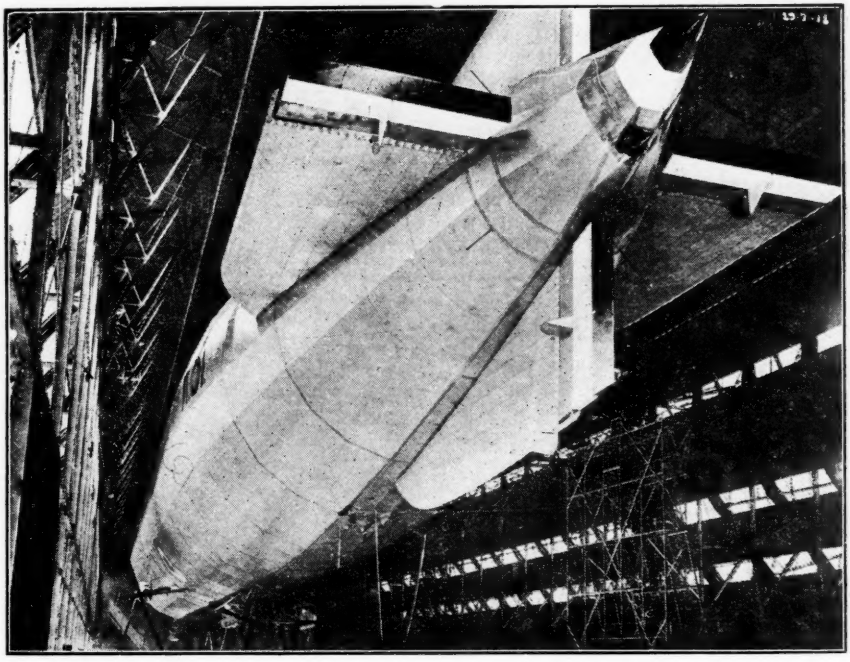


FIG. 1.
The stabilising surfaces at the stern of a rigid airship.

speed of the ship—the law of this variation not having yet been exactly determined. Hence it is not yet possible to predict what the fin area should be from theoretical considerations, and recourse must be made to experience with existing fin areas and the known capabilities of the ship in flight.

For the purpose of comparison of different ships, a factor

$$\frac{(\text{total fin area}) \times \text{length of ship}}{\text{Volume of ship}}$$

has been taken. This assumes that the instantaneous centre of rotation of the ship is very near the bow. The proportions of the moving surface and the total

plane surfaces (fixed and moving) for various ships are given, together with the fin factor as defined above, in Table III.

TABLE III.

Ship.	Fin factor = (Total fin area)(length of ship) / Volume of ship.		Controlling surfaces / Total fin area.	
R.23	1.31	1.01	0.284	0.268
R.29	0.913	0.92	0.252	0.250
R.31	0.79	0.68	0.274	0.310
R.33	0.825	0.62	0.231	0.250

For guidance in using Table III. it may be mentioned that experience with the actual ships in flight indicates that R.23 and R.29 are overstabilised, *i.e.*, difficult to turn. R.33 on the other hand is slightly understabilised and her controlling surfaces are too small, *i.e.*, the moment exerted by the controlling surface does not very quickly overcome the instability of the ship.

The point is of some importance, since if the ship is understabilised it is necessary to use the elevators or rudders continuously to keep her on a definite course, so that a portion of the controlling power is sacrificed and also the speed over the ground due to the alterations in course.

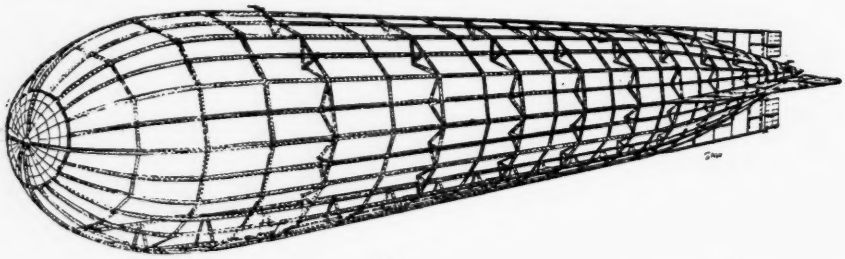


FIG. 2.

Structural Strength of the Ship.

The determination of the strength of the various components of the airship and the design of these parts so as to obtain with the least possible weight of material the requisite strength of part, is the most difficult work in airship design. As with most design work, the process is necessarily tentative and dependent on previous experience. The method of procedure is to make certain assumptions, and with these to work out the stress in the part. By comparison of the stress so obtained with that obtained with the same assumptions on a previous successful ship, a judgment can be formed as to the suitability of the design of the part.

The following remarks will apply particularly to the type of rigid airship known as the Zeppelin or Schutte-Lanz, *i.e.*, when the structure is built up of a number of longitudinal girders running throughout the ship, connected at intervals by transverse girders forming a frame round the ship (Fig. 2). This scheme of construction has been found to give the lightest ship and to be most readily adaptable to use in very large ships. Considering first the ship as a whole. At any section there will be a bending moment and a shearing force in the vertical plane due to a combination of the static forces (*i.e.*, lift and weight) and aerodynamic forces (due to air pressure on the outer cover when the ship is running trimmed by the bow or the stern); and a bending moment and shearing force in the horizontal plane due to aerodynamic forces when turning. To meet

these bending moments and shearing forces we have a built up structure consisting of successive panels round the ship formed by the longitudinals and transverse girders, each panel being internally braced by wires, called diagonal wires (Fig. 3).

It is assumed that the whole of the forces due to bending moment are taken by the longitudinal girders; the distribution of stress being according to the well-known beam formula

$$P = My/I.$$

y being measured from the neutral axis of the ship's section; I being measured by the product of the area of the continuous members of the longitudinal girders and the square of the distance of their centroid from the neutral axis of the ship.

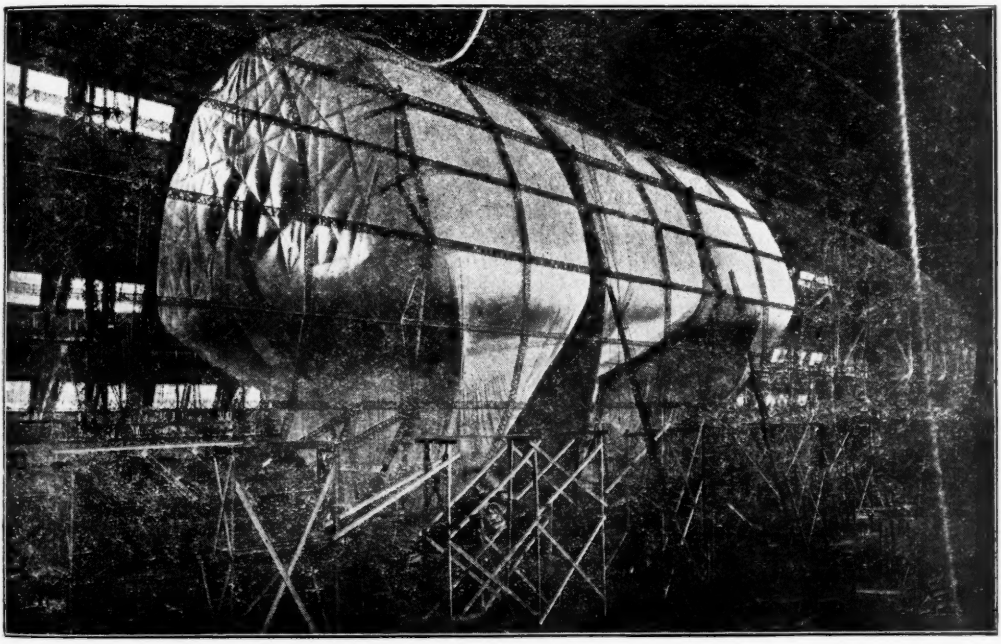


FIG. 3.

*R*33, *showing longitudinal and transverse framework, diagonal wires, etc.*

For the purpose of this calculation, all continuous main longitudinal girders, including those in the corridor, are included.

The shearing force is assumed taken entirely by the diagonal wires. For the simple diagonal wire system, *i.e.*, with the wires being contained entirely in the one panel, it can be easily shown that the tensions in the wires which take the shearing force at a frame are given by the formula

$$\frac{S.F.\ L\ .\ A \sin\phi / \Sigma A \sin^2\phi}{D}$$

where $S.F.$ = Shearing force at the frame.

$L.$ = Length of wire in the panel.

$D.$ = Length of side of transverse frame.

$A.$ = Area of cross section of diagonal wire.

$\phi.$ = Angle which panel containing the wire makes with the horizontal plane.

The summation Σ is taken over the whole section.

Obviously at any one section, only the wires running in one direction will be stressed, whilst those in the opposite direction will tend to become slack. The wires which will be in tension can be readily ascertained from the sign and slope of the shearing force in the shearing force diagram.

In addition to these stresses due to being a part of the ship's structure, the longitudinals are subjected to lateral loads due to the gas pressure. Each longitudinal is assumed to take the gas pressure on a panel of width on either side of the longitudinal equal to half the spacing of the longitudinal girders from each other. The gas pressure is obtained from the formula

Pressure in kilograms per sq. metre =
maximum blowing off pressure of automatic valve in m.m. water above atmosphere
+ height of base of longitudinal above automatic valve in metres × 1.09.

The pressure obtained from this formula is the maximum that can be obtained in practice, and corresponds to the ship rising rapidly near the ground. Further the pressure of the air on the outer cover due to motion is, in general, in the opposite direction to the gas pressure, and consequently tends to diminish the lateral load. Hence the stress obtained from the combination of the end load and lateral load as calculated above is in general the highest that can occur in flight.

The maximum lateral load will occur on the top longitudinals. It is, therefore, extremely desirable that the top longitudinals should be in tension rather than compression. *Hence the distribution of loads should be such that the static bending moment at any section of the ship in all conditions should be hogging, i.e.,* tending to put the top longitudinals in tension. This principle, incidentally, is also used in some types of semi-rigids, the top longitudinals being replaced by fabric, which is thus always in tension.

With a view to decreasing the lateral load on those longitudinals which in addition have to take an end load due to the bending moment on the ship, in R.33 and similar ships intermediate longitudinals have been fitted. The end connections of these intermediate longitudinals are so arranged that the lateral load is transferred to the main frames whilst practically no end load comes on the longitudinals.

The stresses in the main longitudinals are obtained from the generalised equation of three moments, assuming that each girder is continuous throughout the ship, and that the deflection at each transverse frame is zero. The necessary conditions for obtaining the bending moment are obtained by assuming that in the parallel body the slope of the girder at the transverse frame is zero.

The transverse form of the ship is maintained principally by means of wired transverse frames. These frames are called main transverse frames. The gasbags are then fitted intermediate between these frames, each bag being entirely self-contained. Intermediate frames are fitted between the main transverse frames at equidistant intervals (Fig. 3). The greatest stresses occur in the main transverse frames when one gasbag is full and the adjacent one empty. The pressure of the gasbag on the transverse wiring in this condition puts a tension in the wires, which in turn causes a compression in the girders of the frame. The amount of the tension in the transverse wiring can only be calculated with any

degree of accuracy for the purely radial system, *i.e.*, when the wires radiate from a centre ring and run one to each joint. For this case it can be shown that the tensions in the wires—which are all assumed to be of the same size—are practically equal, and given by the formula

$$T = C \sqrt[3]{A} \cdot R^2$$

where A = area of each wire.

R = length of wire from the centre ring to the joint.

C = a constant depending on the number of sides to the frame and how the centre ring is fixed.

Hence for similar ships or for similar sections of the same ships, to obtain the same stress in the radial wires, the area of the wire should be such that

$$A/R^3 \text{ is constant.}$$

It is seen that the tension varies as the square of the radius, so that in larger ships it tends to become very great. It may be reduced by keeping the centre ring from deflecting outwards, *i.e.*, by fitting an axial wire joining all the

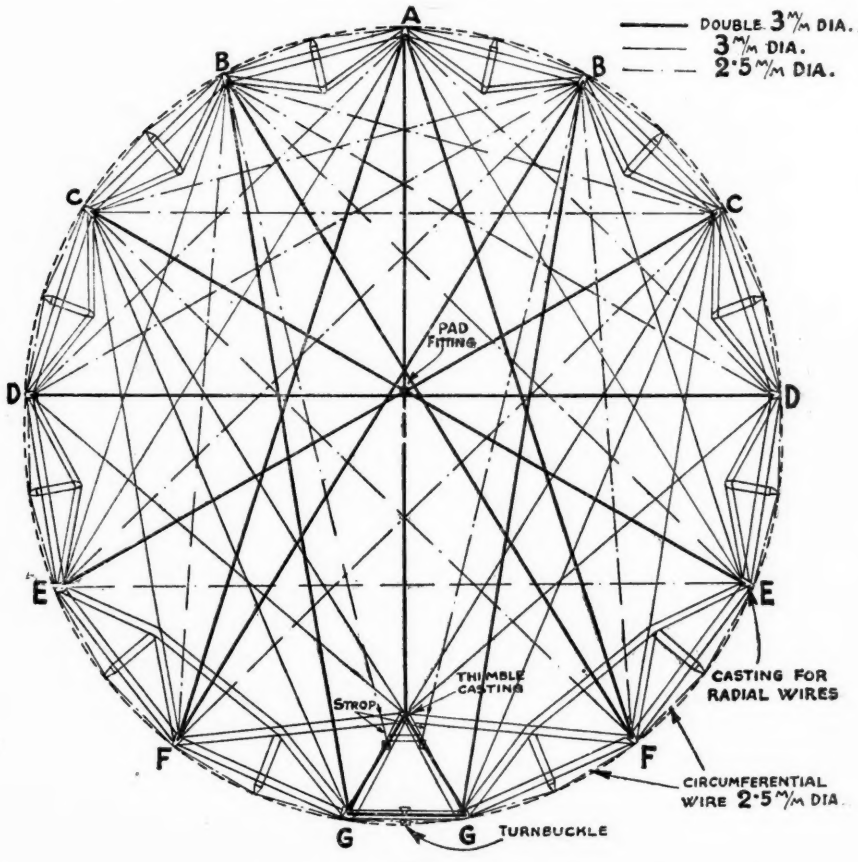


FIG. 4.

Transverse wiring of a main frame.

radial rings together through the ship. This has been done in R.33 and later classes.

In general, in addition to the purely radial system, chord wires are fitted to assist in breaking up the unsupported areas of gasbag fabric (Fig. 4). The loads in the main transverse frames are then compressive ones due to the components of the tensions in these wires acting through the point of attachment, and to the components of the tensions in the diagonal wires acting through the diagonal wire lugs. Of these, the loads due to components of the radial and chord wires are by far the most important, and the transverse girders are designed primarily to withstand these.

In R.33 and similar ships, with a view to avoiding lateral loads on the main transverse girders due to the reaction of the intermediate longitudinals, a kingpost and trusses were fitted on each girder, so that the lateral load is transferred to the joints of the main longitudinal and main transverse frames.

Spacing of Transverse Frames.

The spacing of the transverse frames, both main and intermediate, is a matter requiring considerable judgment. It is obviously desirable from the point of view of weight that the main or wired frames should be as widely spaced as possible, so that the number of gasbags—and therefore their weight—should be reduced, and the weight of the transverse wiring saved. On the other hand with too wide a spacing the longitudinals and keel are not so effectively supported, and the loss of lift and risk of destruction through deflation of any one bag are greater. It is very desirable to concentrate heavy loads, such as cars, ballast, petrol, etc., at the main transverse frames, consequently the spacing of these frames is determined to a certain extent by the position of these items—more especially that of the cars. It is usually desirable to space the frames as far as possible equidistant. In R.33, which is 24 metres in diameter, the main frames are spaced 10 metres apart, with one intermediate frame five metres from the main. In L.70, which is of the same diameter, the main frames are spaced as far as possible, 15 metres apart, with two intermediates five metres apart. The latter ship, however, vibrated considerably at high speeds. This was remedied by supporting the corridor at intermediate frames by wires through the gasbag to the top of the ship (Fig. 5).

Keel or Corridor.

It was formerly assumed that a keel strong enough to take the whole of the shearing forces and bending moments of the ship was necessary, and the earlier ships were designed on this principle. The longitudinals and diagonal wires were considered solely as maintaining the form of the ship, and not as an integral part of the strength structure. This involved a wasteful distribution of material, and in R.29 the keel as a strength member was entirely abandoned. This ship was designed practically on the principles formulated in the early part of this paper, and has proved to be quite successful in practice.

With the increase in the disposable lift in later ships, it was found impracticable to concentrate the dischargeable weights at main transverse frames, as was done in R.29, and an internal corridor was introduced to carry these loads. An internal corridor is preferred to an external, as although there is a certain loss of gas volume, the effect on the speed, stability and controllability in flight is *nil*, and the overall height of the ship is considerably reduced. The strength of the corridor is calculated on the assumption that it is a continuous girder supported

at main frames only and loaded to its maximum capacity. For lightness it is clearly desirable that the loads, such as water ballast, petrol, stores and merchandise, should be concentrated as near as possible to the main frames.

The corridor further provides the means of access between the various cars, and to all other positions in the ship requiring attention during flight. The control wires to the rudders, elevators, gas and water ballast valves and to the engine-room telegraphs are in general led along the corridor and are thereby readily accessible.

Access to the top of the ship is provided by means of access shafts between two adjacent gasbags—except for any special reason only one access shaft is usually fitted.

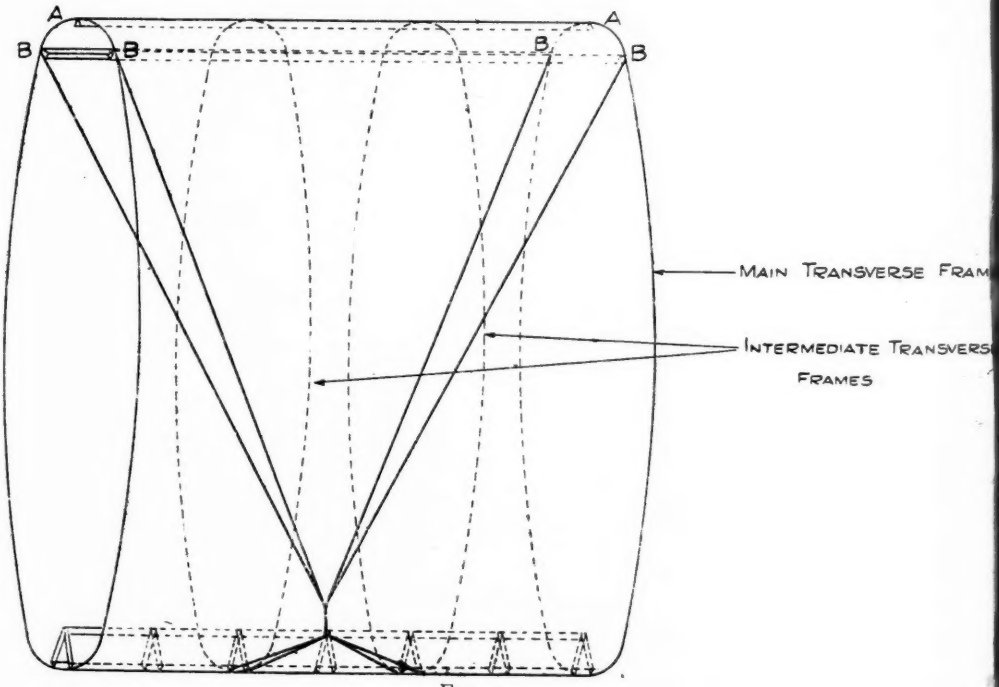


FIG. 5.
Wire support to corridor, L70.

Design of Girder Work.

The design of the girders offers perhaps a wider scope for originality and improvement than the design of any other item in the ship. The requirements in general are :—

1. They should be capable of being easily and accurately constructed.
2. They should allow of simple and light connections to other girders.
3. They should be such that fittings can be easily attached to them, more especially wire lugs.
4. In the case of those girders in contact with the gasbags, they should be free from projections or sharp corners likely to injure the bag.

Theoretically the most efficient strut is a tube, which may be either duralumin, wood or steel. Practically, however, the weight of the joint at the junction of transverse and longitudinal girders with tubular construction is such that together with the weight of girders, the total weight of hull is greater than that when the girders are built up and triangular in shape. In ships of the present type, *i.e.*, up to about 3,000,000 cubic feet gas capacity, the greatest efficiency of construction is obtained by using either duralumin or wood built-up girders. For very large ships, however, it is probable that the loads in the girders will be such that steel can be used in such thicknesses as to make a steel ship a practical proposition.

Duralumin triangular girders are made up of three channels forming the corners, joined by bracing pieces. The strength of this type of girder in compression can be found from the formula

$$(ey/k^2) \sec (\pi/2 \ . \ l/l_0) = (f - p)/p$$

where l = length of strut.

p = failing stress measured by $\dfrac{\text{crippling load}}{\text{area of continuous members}}$.

f = failing stress in compression of a length of channel equal to the span of the bracing piece.

y = distance of channel which fails from the neutral axis of girder.

k = least radius of gyration about the neutral axis.

$l_0 = \pi k \sqrt{(E/p)}$ where E = modulus of elasticity for the materia'.
= 4,700 tons/sq. in. for duralumin.

e = equivalent eccentricity of loading.

The value of e must be deduced from experimental results. For triangular struts, as used in R.33, its value may be taken as

.03 × least radius of gyration.

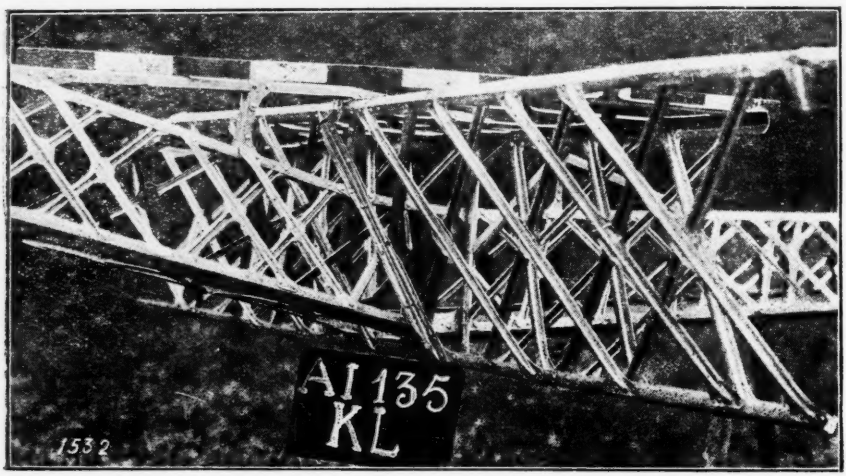


FIG. 6.

Typical joint of main longitudinal and intermediate transverse, Zeppelin type.

The dimensions of the girders generally used are such that l/k approximately = 50.

If the girders are used entirely in compression they are equilateral, if they have to bear in addition lateral load they are isosceles with the greatest depth in the plane of the lateral load.

Wooden girders have been used in some types of ships, notably in R.31 and R.32, and in the German Schutte-Lanz ships. In the Schutte-Lanz ships the girders are built up of three-ply aspen wood stuck together with cold casein glue.

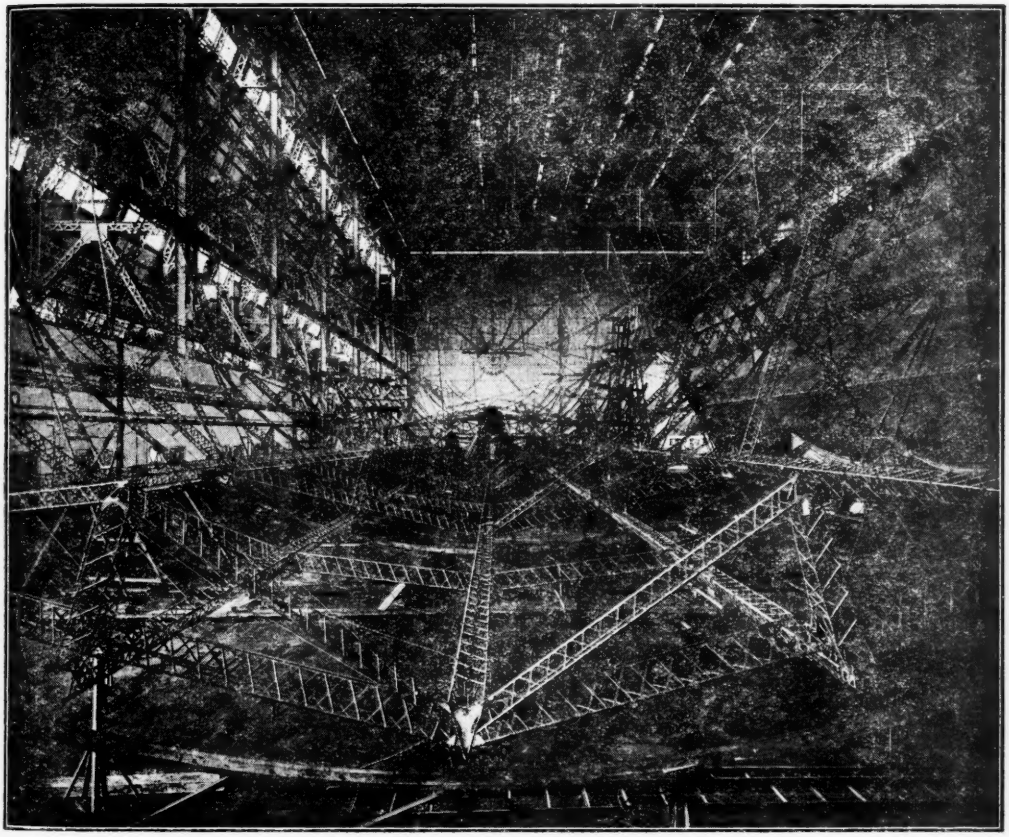


FIG. 7.

General structure of R34, showing method of forming joints of main transverse girders and of longitudinal girders with transverse girders.

In R.31 the corner pieces were made of spruce, fashioned to form a closed cell, and the sides of three-ply aspen, lightened as necessary, the whole being stuck with cold glue. Wooden girders have to be varnished for protection against moisture. It is essential that all girders should be rigidly joined together. This rigidity is secured in duralumin built up girders by butt strapping the respective channels each to each, and carrying the bracing pieces as far as possible through from one girder to another (Figs. 6 and 7). When the girders meet at an angle,

such as the girders making up the transverse frame, bent pieces of duralumin plate join the corresponding faces of the girders.

It is also essential that the continuity of strength should be everywhere preserved.

Gasbags.

The gasbags in a rigid airship are protected from the effects of the weather and direct sunlight by the outer cover, so that no special precautions are required in this connection. Care has to be taken that the gasbags are effectively supported by wires, nets, girders, etc., and that all sharp edges or corners likely to injure the bag are covered (*cf.* Fig. 3).

The material generally used is a skin-lined fabric. The skin is goldbeater's skin, which is the outer coat of the caecum or blind gut of the ox. Other skins, such as beef casing, which is one of the coatings round the intestines of a cow, have also been successfully used. A good goldbeater's skin is practically impermeable to hydrogen. The fabric used is usually a high quality cotton, the strength and weight being dependent upon the size of the bag and maximum pressure. The standard cotton fabrics in this country are as shown in Table IV.

TABLE IV.

Quality.	Weight. grms./sq. metre.	Strength. kilograms/metre width.
A	130	1250
B	110	1100
Bx	90	900
C	80	800
Ck	80	900
D	65	650
E	45	510

An interesting fabric which was used by the Germans in L.70 was jap silk, having a weight of 30-35 grams/sq. metre and a strength of 435 kilograms per metre.

The fabric used in R.33 class airships was Ck cotton weighing 80 grams per sq. metre.

The maximum tension in the fabric is assumed to be given by the relationship

$$T = pR \text{ kg./metre}$$

where p = pressure of gas in kilograms per sq. metre.

R = radius of bag in metres.

Each gasbag in the ship must be provided with an automatic valve to enable the gas to escape when the ship is rising and so prevent excess pressure in the bag (Fig. 8). The position of this valve must be such that it is unaffected by changes in the air pressure on the outer cover and is also easily accessible. This is attained in recent ships by fitting the valve on the flat end of the bag just above the corridor, and carrying off the gas to the top of the ship by means of a ventilation trunk between the gasbags. In R.23 class, valves were fitted on the outside horizontal diameter, and trouble was experienced in these ships through the forward valves blowing off at other than the designed pressure. The initial setting of the automatic valve and the strength of spring and opening should be such that when the ship is rising at her maximum rate the pressure at the top of the bag does not become excessive. The valve, as fitted in the parallel body of R.33, was set to blow off initially at 14 m.m. of water, the tension of the spring and opening being such that when the ship was rising vertically, at say 2,300 ft. per minute, the maximum blowing off pressure was approximately 25 m.m. of water, corresponding to a pressure at the top of the bag of approximately 46 kg./sq. metre.

In addition to the automatic valve a manœuvring or hand-operated valve (Fig. 9) is usually fitted at the top of some of the bags, chiefly for the purpose

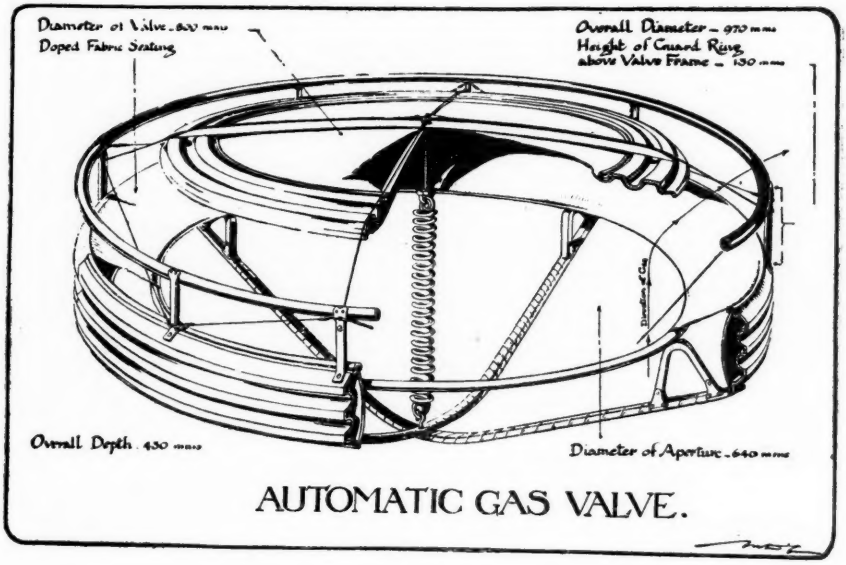

Diameter of Valve - 800 mm
Doped Fabric Seating
Overall Diameter - 970 mm
Height of Guard Ring above Valve Frame - 130 mm
Overall Depth - 430 mm
Diameter of Aperture - 640 mm
AUTOMATIC GAS VALVE.

FIG. 8.
Automatic valve as fitted in R34 class.

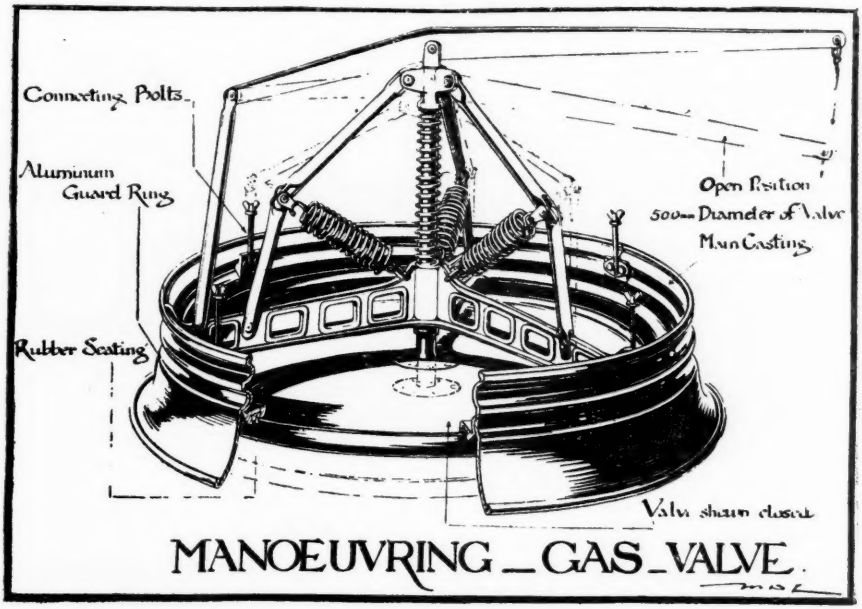


FIG. 9.
Manœuvring valve.

of enabling the pilot to valve gas in landing should the ship become too light. As a general rule these manœuvring valves should not be fitted to the after bags, as it is desirable with the very fine tails now used always to retain as much lift as possible aft.

When the ship rises into air of less density and pressure than as stated above, the gas in the bags expands and blows off through the automatic valves. If the ship subsequently descends, although the total weight of gas contained within the bags is unaltered, the volume which it occupies is necessarily decreased. The

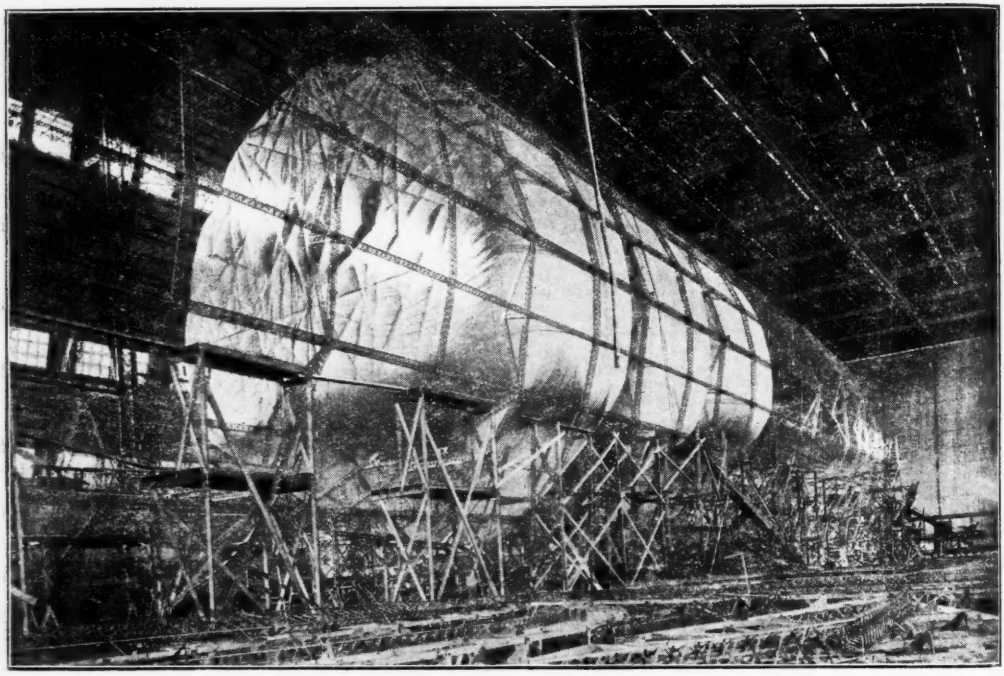


FIG. 10.
Gasbags in place in R34, showing "flat" formed at bottom of bag when partially deflated.

bag consequently is only partly full and the bottom of the bag rises. The shape of the bag in this condition is remarkable, as the bottom forms an absolute "flat" and gives a very good indication of the degree of fulness of the bag (*cf.* Fig. 3). Care must be taken that all fittings on the bag which are, in addition, attached to the structure of the ship, are arranged to allow for this movement without causing excessive tension in the fabric. This is in general accomplished by fitting cones or sleeves of fabric between the gasbag and the fitting.

Outer Cover.

The outer cover consists of a number of panels of doped fabric stretched over the outside of the ship for the purpose of providing a fair surface and to protect the girderwork and gasbags from weathering and exposure (Fig. 10).

The fabric may be either cotton or linen, the dope is usually a cellulose acetate dope. The total weight of doped fabric should not exceed about 120 grams per

sq. metre. The requirements for the dope in rigid airships are essentially different for those for aeroplanes. It is of the utmost importance that the weight of the dope applied should be as small as possible, but at the same time water-proofness must be assured. Tautening is not of material importance. If the dope is applied to the fabric before the latter is made up into the ship, it must be sufficiently flexible not to crack when the fabric is folded. The most satisfactory procedure is to apply the preliminary coats of dope by machine before the fabric is made up, and the final coat when the fabric is in place on the ship.

The colour of the dope depends upon the service to which the ship is being put. For tropical work zinc white or aluminium powder is preferred, owing to the necessity of avoiding superheating of the gas as much as possible, and also to protect the fabric against tendering. During the war the Germans coated the under portion of their ships with a black dye dope, and the upper surface a mottled colour. This, of course, was for night work.

When excessive pressure is likely to occur on the outer cover, as for instance forward owing to the air pressure on the bow, or in wake of the propellers, wire or girder stiffening should be provided for support. Formerly heavier covers were fitted in these positions, but this has been found not to be necessary.

Factors of Safety.

The factors of safety to be given to the various items of an airship naturally depend on the degree of reliability which may be placed upon the assumptions, the probability that the stress in the part concerned may become greater than that calculated, and the nature of the forces which come upon the part. For items subjected to vibratory or shock loads, such as car suspension wires, a high factor of safety is necessary. The worst case that can generally occur is when the ship is either climbing or diving at its maximum rate, and a factor of safety of at least four to six should be obtained in the car suspensions under either of these conditions. On the other hand, on items which cannot have a load in them beyond a certain maximum or when the assumptions made are the most extreme, such as for instance, the gasbags, and longitudinals in the first case, or the transverse frames in the second case, a large factor of safety beyond the calculated load is not necessary or indeed desirable, as the weight of the part is increased thereby.

It is difficult however to generalise on what the factor of safety should be, and the choice of any particular figure usually depends on the individual designer and previous experience.

Handling and Mooring Arrangements.

When the ship is in the shed and partially deflated, it is desirable to support her as much as possible in order to prevent deformation of hull. This is done by fitting strops to the joints of the top longitudinals and main transverse frames, and slinging the ship from these to the top of the shed. Lugs are also provided at the inboard elevator pintles for the same purpose. The cars are supported in cradles from the ground.

For handling the ship on the ground, arrangements must be made for a trail rope forward and aft which can be dropped when the ship is within 500 feet of the ground. These trail ropes, which should be as far forward and as far aft as possible consistent with the strength of the ship, must be capable of being released from the control car. In addition, at frequent intervals along the ship, handling wires should be fitted about 25 feet long with a bight on the end, to which toggled ropes can be attached. These arrangements should allow for the greatest restraining moment to be put on the ship with the least force.

If the ship is to be moored to a mast, special stiffening in addition is necessary in the bow. As the greater pull comes on the ship at the forward trail rope, special care is necessary to distribute this load as equally as possible from this point, throughout the structure. This is accomplished in Zeppelin ships by attaching the mooring point to a wire system whereby the strain is distributed

vertically over a transverse frame, and horizontally along the corridor and framework of the ship.

Distribution of Fixed and Non-Dischargeable Weights.

The fixed weights of the ship are mostly determined by structural considerations, and their position cannot be altered. In the design stage, however, a certain amount of latitude is allowable in fixing the position of the cars. These should be so arranged that the propellers do not mask each other, and also that when the ship is at rest at her maximum static height, with all gasbags full, and

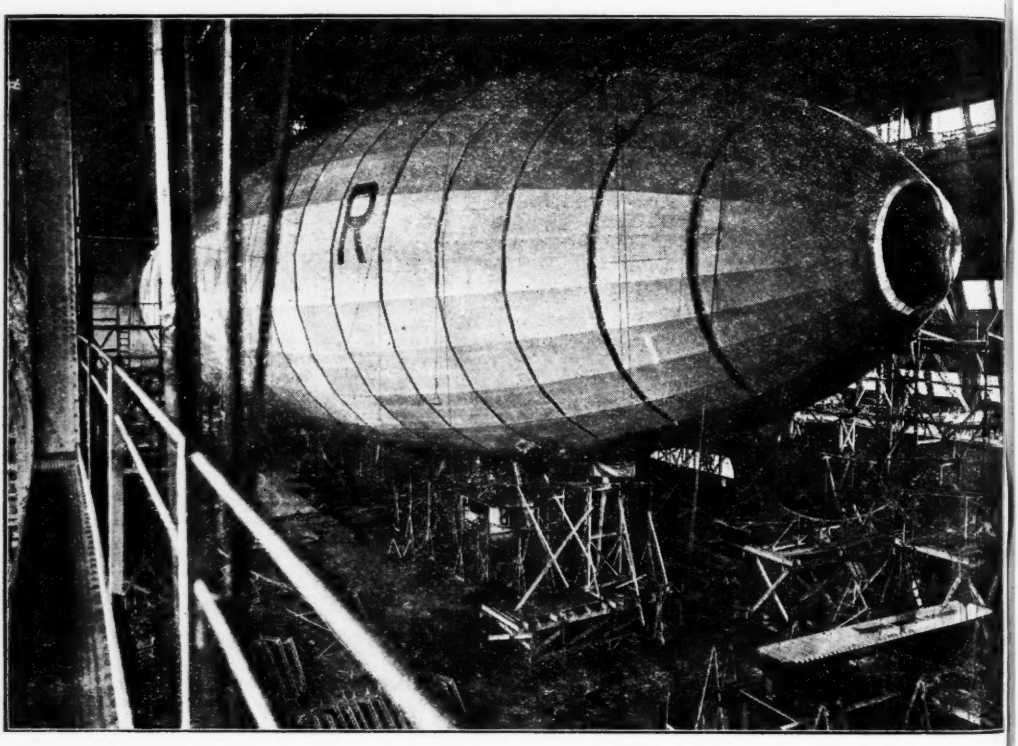


FIG. 12.
R34, showing outer cover being laced into place before sealing strips are put on.

with the non-dischargeable weights in their appointed positions, there is a moment by the stern. This is always preferable to a moment by the bow.

At least two wing cars, one on either side, should be fitted as far up the side as possible, so as to enable manœuvring to be carried out near the ground if necessary without any danger of the propellers hitting the ground.

The landing ballast should be distributed so as to allow the pilot to change trim quickly if necessary when landing. For this purpose, it should be divided as far as possible aft and forward consistent with strength. Average figures are :—

Forward landing ballast 1.5 to 1.75 per cent. of total lift.
Aft landing ballast 1.5 to 1.75 per cent. of total lift.
Midships landing ballast 1 per cent. of total lift.
Total, 3.5 to 4.5 per cent. of total lift.

The landing fuel is of necessity stored as near as possible to the various power units in the fixed petrol tanks.

Distribution of Dischargeable Weights.

The dischargeable weights can be divided for the purpose of distribution under three headings :—

Ballast,
Petrol and oil,
Stores.

The petrol and oil should be distributed in relation to the position of the engines, and should be such that at any trim that the ship may take up, there is always an adequate supply to the engines. In recent ships the petrol has been carried in aluminium tanks suspended from the corridor, each tank carrying 200 or 300kg. petrol. The tanks are so arranged that they can be slipped and discharged overboard in case of emergency. Certain tanks are, however, made fixed for use as service tanks.

The water ballast is carried in fabric bags, each carrying approximately 1,000kg. (one ton) of water, suspended in the corridor. The ballast is discharged outside the ship through a valve at the bottom of the bag and a fabric hose or aluminium pipe, time of emptying bag being 65 seconds.

In general, an excess number of positions for ballast bags and slip petrol tanks are provided beyond the number actually required in the " standard " conditions, to allow for variations in initial lift due to atmospheric and purity conditions, and to allow the pilot as wide a range as possible for trimming the ship.

Horse-Power and Speed.

The resistance to motion of an airship is made up of :—

1. Resistance of the ship's form.
2. ,, ,, fins, rudders and elevators.
3. ,, ,, cars and propellers, if any of the latter are fixed.
4. ,, ,, external wires, such as fin interbracing wires, gondola suspension wires, struts, etc.
5. Miscellaneous resistances, such as radiators, ladders, etc.
6. Augmented resistances due to wake of propellers.

Model results are usually given for (1) only. They are expressed in terms of the resistance coefficient

$$C = R/\rho v^2 V^{\frac{2}{3}} \text{ and } vV^{\frac{1}{3}}$$

where R = resistance of ship's form.
v = speed.
V = volume of air displaced by ship's outer form.

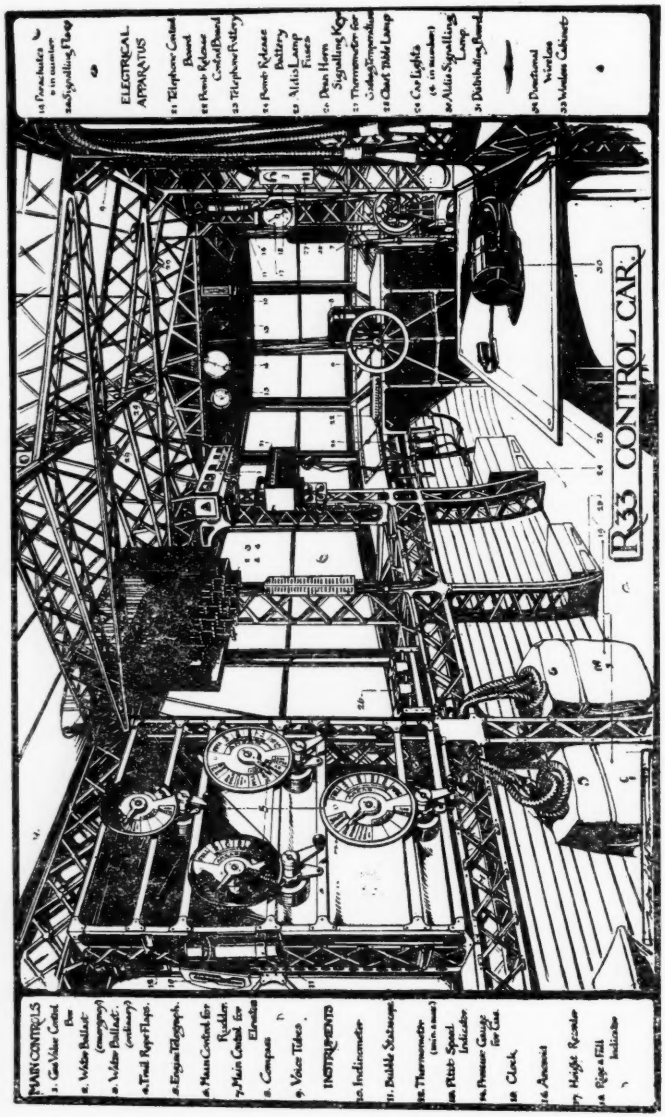
From theoretical considerations, using the principle of dynamical similarity, C should be the same for similar ships for the same value of $vV^{\frac{1}{3}}$. The maximum practical value of $vV^{\frac{1}{3}}$ in the wind channel for, say, a 1/120th size model, which is obtained for an air speed in the channel of 80 ft./sec., is only 1/88th of that for the full-sized ship at 40 m.p.h. The law of variation of C for values of $vV^{\frac{1}{3}}$ between these two limits is not known. Hence the prediction of the resistance results from model experiments cannot yet be done with any degree of accuracy. From trials on ships running at a constant height, it has been established that by running various combinations of engines at full power, then

$$\text{Total B.H.P.} \propto (\text{speed})^3.$$

If speed is measured in miles per hour, then for a ship similar in form to R.33, and with the same efficiency of propellers and gearing, approximately,

$$\text{B.H.P.} = 0.0058 \times (\text{speed in m.p.h.})^3.$$

To obtain the B.H.P. required for a similar ship of different displacement it is sufficiently accurate to a first approximation to take the B.H.P. to vary as (total lift)$^{\frac{3}{2}}$.



General arrangement of control car, R33, showing position of water ballast and manœuvring valve controls, steering and elevating hand-wheels, etc.

The weight of machinery and engine car may be assumed to vary directly with the horse-power, though care must be exercised in using this rule owing to improvements in design. An average figure given by Mr. Campbell before the Institute of Naval Architects was 10lbs. per B.H.P.

Proportion of Fixed Weight to Total Lift.

The efficiency of a design is measured by the relative values of the fixed weights to the total lift—the lower this ratio the more efficient the design. As previously explained, the fixed weight is made up of hull, fabric and miscellaneous weights and machinery and car weights. The last set depends upon the speed, and to a first approximation for present designs of engines, may be taken as

$$W \text{ in lbs.} = .0038 \times (\text{max. speed in m.p.h.})^3 \times (\text{total lift in tons})^{\frac{2}{3}}.$$

Miscellaneous weights to the total lift measures the efficiency of the design from the ship designer's point of view. Values of this ratio for various German ships, assuming weights of machinery and cars are given by 10lbs. per B.H.P., are given in Appendix I.

No law can rationally be given as to the variations of the remaining fixed weights to total lift, as the design of the various parts is so far not advanced sufficiently to enable any deduction as to the variation of weight with dimensions to be made. As illustrative of this, it is interesting to refer to Appendix I, where it is seen that with practically the same total lift, the weight of hull, fabric and miscellaneous items was reduced from 28.9 tons in L.33 to 19 tons in L.65.

Subsequent Developments.

This paper has dealt almost entirely with the principles of airship construction with special reference to the Zeppelin types. Of all types which have been examined this appears to be the most practical and promising form, the development of which has been marked by the greatest progress. It also lends itself most readily to adaptation to larger sizes, principally on account of the relatively economical disposition of material from an engineering standpoint. As mentioned previously in the paper, the actual design of girders, however, will most probably be materially and radically modified, chiefly by the introduction of steel in construction, and possibly some saving in weight by the use of welding instead of riveting. With present sizes of ships the thickness of steel sections, however, would be so small as to be impracticable.

Another item which will profoundly influence the type of construction is cost. Steel construction will be much cheaper than duralumin, both in material and labour.

Developments in gasbags may be expected in the direction of finding a substitute for the expensive goldbeater's skin. Various substitutes have been tried, but so far have not proved successful, for although a compound may look promising on a test piece, yet when worked into a bag and crumpled, it usually has a high permeability. The relative merits of gastightness or lightness have not yet been satisfactorily settled; if gas is expensive, as for instance helium, then gastightness is of prime importance. Helium, however, has a permeability of only about 0.65 that of hydrogen, so that the loss of helium through the bag will probably be less than the present rate of hydrogen. The Germans, however, appeared to have attached more importance to light weight, relying on the frequent purging of the gas through refilling after flight to maintain the requisite purity.

It is probable that the outer cover will remain doped fabric. Aluminium plate, even in the thinnest sections, would be too heavy and would require to be very carefully supported.

Conclusion.

I am indebted to Sir Eustace d'Eyncourt, K.C.B., the Director of Naval Construction, for permission to read this paper, and to the Air Ministry for permission to publish the information contained therein.

GERMAN ZEPPELIN RIGID AIRSHIPS.

APPROXIMATE DIMENSIONS, ETC.

Type.	L.7	L.14-15	L.33	L.41	L.49	L.65	L.70	L.71
Date of completion	1913-14	1915	1916	1917	1917	1918	1918	1918
Length (ft.)	453	536	645	645	645	645	694	743
Diameter (ft.)	—	61	78.7	78.7	78.7	78.7	78.7	78.7
Gasbag capacity (ft.)³	836,000	1,128,000	1,942,000	1,942,000	1,942,000	1,972,000	2,196,000	2,420,000
Total lift (tons)	25.4	34.2	59	59	59	60	66.7	73
Disposable lift (tons)	—	15.15	23.7	30.3	33.0	34.3	39.3	45
Total B.H.P.	480 (?)	720	1,440	1,200	1,200	1,300	2,100	1,800
Weight of hull (tons) (assuming machinery and cars = 10 lbs. per B.H.P.)	—	15.9	28.9	23.4	20.6	19	19.25	20.0
Percentage, weight of hull/total lift	—	46.5	49.5	39.6	34.9	31.7	29.3	27.4
Dischargeable weight (tons) (approx.) (assuming non-dischargeable = 9% total lift) ...	—	12	18.4	25	27.6	28.9	34.3	38.4
Maximum static height (ft.) ...	—	13,300	11,500	17,000	19,400	20,000	22,000	23,000
Maximum speed (m.p.h.) ...	43.5	47	60	60	60	68	73.5	72

NOTE.—The weight of cars and machinery per B.H.P. in classes later than L.65 is less than in earlier classes owing to the introduction of direct drive of propeller and light cars.

DISCUSSION.

The CHAIRMAN said the Paper had been of great interest and he hoped that the discussion would be sufficiently thorough to confirm or refute the various maxims Mr. Cole had laid down. He had hoped that Mr. Johns, who was in charge of the early rigid airship construction in this country, would have been present to discuss the Paper, but he was unable to attend.

The following written communication sent to the Chairman by Mr. JOHNS was read by the Secretary :—

The various formulæ given by Mr. Cole in his Paper and which I understand were arrived at by him when engaged on airships in the Department of D.N.C., have proved extremely useful in the design of airships. They cover a great portion of the details of the ship, and that they are sufficiently correct for all practical purposes has been confirmed by comparison with the actual dimensions of the details fitted in German airships. When one considers that in ordinary sea-going ships the design portion of the problem was wholly developed from experience and that the theory lagged centuries behind, one is forced to the conclusion that so far as airships are concerned the designers are at a great advantage in having such information as that given in the paper. For instance, in connection with the stabilising and controlling surfaces required for airships Mr. Cole and the staff of the N.P.L. together considered the question of the stability of airships generally, and arrived at certain expressions by which the stability or otherwise could be determined by experiments on models. Now in the case of ordinary water ships such an investigation has not yet been made and the determination of rudder sizes is still a method of rule of thumb. It is, of course, clear that in the case of airships, where the buoyancy of air is so small compared with that of water, one must aim at extreme accuracy, in fact, the accuracy must be about 830 times as accurate as for the surface ship. Such investigations as those made by Mr. Cole with the resulting formulæ given in the paper are therefore of the highest value. I notice Mr. Cole has made no investigations on the stresses in the girder portions of the transverse frames. Very probably the number of parts is redundant and the arrangement does not admit of calculations and experiment must be resorted to. It has often struck me that the present arrangement of transverse girder by which a king-post truss is fitted to the various sides of the transverse frame looks weaker from the point of view of the racking of the frame than if the king-post were fitted at the joints of the straight portions of the frame with the ends of the trusses at the centre of the sides. It would be interesting to get Mr. Cole's opinion on this. Mr. Cole is to be congratulated on his paper and the R.A.S. on the inclusion of such valuable information to its proceedings.

General R. BROOKE-POPHAM said he, perhaps like a certain number of other people there, had come there knowing nothing about rigid airship construction, and he felt that he would go out, if not competent to design an airship, at least capable of criticising other people's designs—for this his best thanks were due to the Lecturer. His practical knowledge of airships was limited to two trips in the old "Gamma" in 1912. On the second both engines broke down and they landed in the middle of a wood. He would like to ask the Lecturer whether there were any structural reasons for limiting the size of airships. People talked gaily about airships of 10 million cubic feet capacity and he wondered whether there was any structural reason against building an airship of that size. The axis of rotation of the propellers of the old airships used to be movable, so that one could put the propeller horizontal to give a lift to the ship, or turn it round to 180 degrees to pull the ship down. He believed that was not adopted on modern airships. Was there any particular reason for giving it up? There were great advantages in the use of helium, the chief one being that it was not inflammable.

A disadvantage, however, was its cost. It seemed that its minimum cost was about 20 times the cost of hydrogen, and it might be as much as a hundred times. Also, according to the figures in the Paper, one lost about 7 per cent. of the total lift, as compared with hydrogen. That loss of lift could not be taken out of the structural weight of the airship, but must be taken out of the useful or commercial load. He would like to hear opinions as to whether the use of helium for commercial airships was a practical possibility. He imagined the loss of 7 per cent. in lift would reduce the useful load by about 30 per cent.

Dr. J. E. PETAVEL said he had followed the development of airships mainly as a spectator, and he had greatly admired the perseverance, energy and skill of men like the Author, and also the Chairman, who had been largely responsible for our present leading position in this branch of construction. The "Mayfly" was essentially experimental, the main purpose of its production being to provide information for future design and manufacture. The ship, unfortunately, was destroyed early in its career, but not before much of the knowledge sought for had been obtained. After this first venture there was a long pause, due partly to the want of faith of the public and partly to the want of imagination of the Admiralty. Meanwhile, the German Government constructed a series of experimental ships with gradually increasing success. The country paid dearly for that hesitation, as the rigid airships proved to be of great value during the war, especially for naval purposes. At present, he thought we were again in a rather critical period at which the progress obtainable by steady research might be interrupted. There were considerable possibilities for the rigid airships in the longer journeys undertaken for commercial purposes and also for scouting and liaison work for the Navy. He hoped the acquisition of knowledge would continue which would enable us to produce a fleet of such vessels which would prove more efficient than our neighbours, should the emergency arise. To attain this it was necessary that the many different branches of the service should go hand in hand. They needed the mathematician, the experimenter and the skilled and trained crew. For a period all these factors co-operated satisfactorily and in two or three years we caught up the progress which the Germans had made through a continuous previous study from year to year. He hoped the team work which was in successful operation towards the end of the war would go on steadily and on a scale adequate to provide the knowledge that this country might one day need.

Mr. C. I. R. CAMPBELL said Mr. Cole resigned his connection with airship design some months ago, and it was extremely creditable to him that he retained such an interest in the work as to come forward and read a Paper of that sort. Without detracting from the value of the Paper, he would like to say that the calculations and methods of calculation in the Paper were not in every case those adopted at the Air Ministry. It did not follow that they were not good, nevertheless. It was necessary that information which came to the Government offices should be brought forward for the use of the manufacturing firms, but the firms should reciprocate. Some of them had made extended experiments and they should place their knowledge at the disposal of the country. Airships were in their infancy—a rather troubled infancy, chiefly from lack of food—and every scrap of information that could be made available for general use was of great value, and he thought it should be done. The information in the Paper would be useful to designers and also, he thought, to the pilots of airships, who would get by reading the Paper valuable ideas to help them in the management of their ships. One got from the Paper an impression of a very simple and complete set of calculations, but behind that calm unruffled surface there were many troubled depths of intricate work, places where one had to rely upon judgment and where the guiding light of calculation became very faint indeed. In regard to those calculations the one thing that stood out was the constant need of more and more information of the type which the N.P.L. had done so much to give them,

and he was extremely glad to see Prof. Petavel and other members of the N.P.L. there that evening. At present the Air Ministry staff relied very much on them to fill in the gaps to improve their knowledge and enable them to get nearer and nearer the complete knowledge of all the loads that came upon the structure from aero-dynamic forces. He felt that the possible future uses of rigid airships in particular were more assured and greater in scope than Prof. Petavel had described them, and he hoped the staff at the Air Ministry would be continually in collaboration with the N.P.L. to add continually to the knowledge at the disposal of the country. It would probably fall to the Air Ministry rather than to commercial concerns to be responsible for introducing new features and developments into airships.

Mr. MAY thought it was perhaps unfortunate that an attempt had been made to deal with the problems of rigid airship design in a short paper. It was not considered that some of the broad assumptions made in the Paper were quite reasonable and they were hardly justified in practice. It was assumed that the whole of the shearing force was taken by the diagonal wiring. This was hardly a fair assumption to make for the tapering portions at the ends of the ship where the longitudinal girders might take as much as 40 per cent. of the shearing force. Also, no mention has been made of the stresses in the diagonal wiring due to the lift of the gasbags. This was very important, especially in the case of an airship having two intermediate transverse frames between each pair of main frames, where a large part of the lift of the middle portion of the gasbag in the vicinity of the two intermediate frames must be taken away to the adjacent main frames, and this must be done chiefly by diagonal wiring. The stresses in the wiring due to this effect might be considerably larger than those due to the general shear of the ship. The longitudinal girders were assumed to take the gas pressure on a panel of width on either side of the longitudinal equal to half the spacing of the longitudinals from each other. If the longitudinal girders were designed to take these loads, it could be definitely stated that the ship would be very inefficient as regards disposable lift. No mention had been made of the gasbag supporting wires which could undoubtedly take most, if not all, of the radial pressure of the gasbags, if designed correctly. It was pointed out that by using Mr. Cole's assumptions for the lateral loading, if the intermediate longitudinals were neglected, the " B " longitudinal in R.33 would be subjected to a loading of 130lbs. per ft. run. If the stresses so obtained were superimposed on those due to the general bending of the ship, the girders would collapse. Although, as stated in the lecture, the ideal arrangement was obtained by distributing the loads so that the static bending moment at any section of the ship in any condition should be hogging, it was impossible to obtain this in practice over the whole length of the ship, because of the full lines of the bow, which always gave in the forward part of the ship a large excess buoyancy over weight, and thus a sagging bending moment in the heavy condition. Further, it was necessary to design the longitudinals to take a certain sagging bending moment, due to aerodynamic forces. Also the stresses set up in the longitudinals due to the longitudinal component of the gasbag pressure on the tapered portions of the ship must be considered. It was stated that the greatest stresses occurred in a main transverse frame when one bag was full and the adjacent one empty. It must, however, be borne in mind that it was possible to obtain even larger stresses with the gasbags full where there was a considerable difference of pressure between two adjacent bags. For example, in R.33, with two adjacent gasbags full, but with one at a pressure of 14 m.ms. of water in excess of the other, larger stresses were set up in the main frames than would be obtained with one deflated gasbag and the adjacent bags just full. Also the deflated gasbag effects were less serious at a height, *e.g.*, 10,000ft., they were only 73 per cent. of those at the ground level, while the effects of difference of pressure were equally important at any height. It was stated that a ship should be designed so that there was

a moment by the stern in the light condition. It would appear desirable that an airship should be designed to be absolutely balanced in the light condition, so that it was not necessary to carry redundant ballast for trimming the ship in that condition, as that reduced the efficiency of the ship. Also, in a ship designed tail-heavy in the light condition, the effect of the ballast required in the forward part of the ship for trimming was to increase the already very high bending moments obtained with the ship in the light condition, and this should be avoided if possible.

It did not appear that the fin factor given by the Author could be accepted as a reliable guide for design purpose. While R.32 was considered stable both in pitch and yaw, it was true that R.33 was slightly unstable in both directions. These two ships had practically the same relative amount of total fin area, and it appeared that the difference in their dynamic stability was due to the fact that the distribution of that area in the two ships was somewhat different, the fins in R.32 being relatively wider and thus shorter than in R.33. This would suggest that a better basis of comparison would be fin factor = total fin area/length of fin × length of ship/longitudinal cross section of ship. With regard to the strut formula given on page 108 it was not quite clear to him how this formula should be used. The whole thing seemed to be based on experiments, and it would seem that if one tested a fair number of girders one could plot various curves of l/k and failing stresses, and get all the information required.

Finally, the assumption that the maximum tension in the fabric of the gasbags is given by the relationship $T = pR$ would be true if we neglected the effect of the nets or gasbag bracing wires. Actually these would relieve the gasbag fabric of practically all its tension due to gas pressure if designed correctly.

Mr. MITCHELL (General Manager of Messrs. Shorts') said the Author had accomplished a feat in compressing into one paper the whole theory of airship construction and the Society was to be congratulated upon having such a Paper added to its records.

Mr. Cole could not go into details of the necessary calculations in the space available, but he (Mr. Mitchell) thought it should be made clear that many of the formulæ given could not be taken as giving definite quantitative results, but should only be used for comparing one ship with another. No one would claim that the simple bending moment formula was directly applicable to a complex structure like a rigid airship, but a more accurate result might be obtained if, on the side of the ship in tension, the tension of the diagonal wires were taken into account. If the longitudinals in the upper part of the ship were in tension a corresponding strain would come on the diagonal wires.

The Author had also given a formula for obtaining the tension of the radial wires. It might be quite correct, but was a little misleading. From this formula the Author deduced that the tension varied as the square of the radius, whereas with equally good design it varied as the cube of the radius, because for the same stress the area of the wire A itself must vary. If one eliminated A in the formula in terms of R it became really " the tension varies as the cube of the radius." From that one could easily deduce that the weight of the wires varied as the fourth power of the radius, in other words, their weight increased at a greater rate than the displacement of the ship. No doubt it was true in many respects to say that the bigger the ships got the more efficient they became; there was an enormous gain in the weight of the machinery and fuel; but as regards the hull there were many parts which must increase at a greater rate than the displacement, and he thought that would have a limiting effect in the practicable size of airships. He believed the formula quoted by the Author for finding the strength of girders had been used very largely for certain classes of girders, but was of very doubtful accuracy for the lightly built up girders used in airships. If the results given by such a formula were compared with practical experimental

work it was found that a simple formula—so many lbs. per square inch of sectional area—gave as good, if not better, results.

It was stated in the Paper that the longitudinals should be designed to take the whole of the gas pressure. He thought that was unnecessary. It would be an inefficient way to use those girders entirely for that purpose when there were diagonal and circumferential wires which could take up a great deal of the stress. Further, it was stated that in the R.33 and later ships the intermediate longitudinals were arranged to take the lateral stresses and not the longitudinal stresses, and at the main frames a king-post with trusses was introduced in many of the intermediate longitudinals. He had always thought that form undesirable and he was glad Mr. Johns had some waverings about it. Mr. Johns suggested that the king-post should be in another place, but he would do away with it altogether. If a radial wire were put in its place he thought it would take up the stress at that point and the weight saved by the omission of the trusses could be used to increase the thickness of the main transverse frame, and a more durable and stronger job would be obtained, besides simplifying construction and reducing cost. Those frames, he thought, were in very much the same condition as regards stress as the rim of a bicycle wheel, and he would be surprised to see a bicycle going along the street with king-posts all round the rim between the spokes.

With reference to the statement that in the more recent ships the spacing of the main transverse frames had been increased from 10 to 15 metres; of course, this involved having larger gasbags, and in ships designed specially for war purposes it was no doubt necessary to go to every refinement and take greater risks to get greater efficiency, but in ships for mercantile purposes it would be wiser to retain the smaller gasbag. With the larger gasbags, if one gasbag burst, about 10 per cent. of the lift of the ship was gone and in many cases sufficient weight could not be jettisoned to prevent the ship coming down.

Mr. Cole thought that in the future steel would take the place of aluminium alloys. He did not think so. One of the greatest objections to the existing ships, especially from the commercial point of view, was the extreme thinness of the various parts. In a girder the Author had dealt with the bracing piece was only .017 inch thick, and the result was local damage by men climbing about the girders, and such thin material was very susceptible to corrosion. He looked forward, in larger ships, to being able to use thicker material, which would largely overcome these objections, but if steel were introduced they could come back to the same position as they were in now.

Major W. H. Smith said he was a little disappointed to see that our designers were following on the lines of the Germans. The information in the Paper showed very little advance in what the Germans had done in the Zeppelin. We had copied them in regard to aluminium girders and woodwork on the Schutte-Lanz principle. We might have struck out in other directions. The cars offered considerable resistance and blocked the transmission between the power units and the propellers behind the cars. Also we still stuck to three or four cabins away from each other and difficult to communicate with. Balloons were another question. With the present design there was considerable waste of gas when rising rapidly and even with the internal ballonets there was a lot to be learnt. It had been suggested that they might build bigger ships in which the balloon might be half full at sea level and expand when they got higher. It would have helped the commercial side of airships if experimental work had been conducted on those lines. It was difficult for private firms to undertake it, and pressure might be brought upon the Government to help such work.

Commander E. S. Land, C.C., U.S.N., had sent in the following communication which was read by the Secretary:—

The Paper by Assistant Naval Constructor Cole is not only very interesting but also extremely instructive. It adds considerable information to that pre-

viously published, it being noted that there is rather a dearth of information along these lines. The lack of published data of this character is unfortunate, and tends to retard the progress of rigid airship work, especially along commercial lines.

It seems to me to be an excellent idea to define definitely the terms used in rigid airship construction, and this Paper will be of material assistance in standardising the nomenclature.

I am glad to note that rigid airship construction is not to be enshrouded in a veil of secrecy which, for so many years, retarded the development of submarines. In the case of submarines, there may have been some good reasons for the secret methods followed by nearly all countries, but there is nothing to indicate that any real advantages were gained. In the case of rigid airships the development of which is somewhat dependent upon their commercial application, it would be a great mistake to retard in any way their development by enshrouding their construction with secrecy, which secrecy is in reality only the ostrich with its head in the sand.

In an infant industry of this character it is extremely difficult to state that there are certain limiting factors in the sizes of the ship. It would probably be much more economical in the long run to anticipate extreme sizes and build our housing sheds accordingly, rather than handicap the development of these ships, due to housing shed restrictions.

In going over this Paper, as well as other papers on the subject, one is struck with the very close analogy to ship construction, particularly submarine construction. If one includes bridge construction, the analogy is complete, as the problems under consideration are capable of solution along the same general lines that are followed in ship and bridge construction. As is well known, the term " fabricated ships " is a coinage adapted from the bridge construction; the combination of fabricated ship construction and ordinary ship construction presents the same problems that are presented in the design and construction of rigid airships.

The analogy between rigid airships and submarines is particularly apparent in connection with the control of these vessels. However, while with submarines, a great deal of dependence is placed upon the use of bow hydroplanes for submerged control, I understand that in rigids such is not the case. This is rather surprising and requires some further elucidation to give one a satisfactory understanding of the reasons therefor.

The construction of rigids is an art and a science combined to the last degree. The question of " factors of safety " should therefore be capable of reduction to a scientific basis. We have been told that " factors of safety " are " factors of ignorance," but this should not be the case in construction of ships of the character of rigids. Neither should the " factors of safety " depend upon the individual designer. " Factors of safety " should be " factors of science," which means that no more weight should be put into the construction than is essential. In the vernacular of the street, " Every cigarette smoker takes a chance," likewise, anyone going to sea in ships or in the air in ships, " takes a chance." This should be taking a scientific chance only. The weights involved in the construction of vessels of this character do not permit covering remote contingencies.

In no type of ship construction is the question of reduction in weight so important as in airships. The efficiency of the design is directly dependent upon this question. It would be well, therefore, to engender a healthy rivalry between the hull designer and the machinery designer on the one hand, and between the designers and the operators on the other, in order to insure that not a single ounce of material is incorporated in the ship unless it is absolutely necessary.

In conclusion, might I add a word relative to the cordial relations existing between Great Britain and the United States in connection with aircraft of all

kinds. This is well exemplified by the construction of R.38 by the Air Ministry, which vessel has been purchased by the U.S. Navy Department. Co-operation between the representatives of the two countries in matters of this kind is bound to result, not only in the mutual advantage of those concerned, but also to the advancement of the science—"control of the air."

Major PRITCHARD said he would confine his remarks to rigid outer cover questions which Mr. Cole had briefly mentioned. Mr. Cole's conclusion that only in tropical countries should an outer cover have a reflecting surface to minimise superheating appeared erroneous. Broadly speaking, the amount of superheating in an airship was proportional to the difference between the sun and the shade temperature at the moment. This difference depended to a large extent on the density of substance between the sun and the ship. In the tropics, near the ground, the air temperature, or in other words, the temperature in the shade, is high. There was, however, no reason for assuming that the difference between this temperature and the temperature in the sun (the temperature inside the hull) was inordinately greater than would be experienced in more temperate regions. In the tropics the rate of decrease in shade temperature (air temperature) with increase in height was greater than in temperate regions. In the tropics this decrease in temperature was at least 4 degrees F. per 1,000 feet. To take the other extreme, in the Polar regions during the spring and autumn, when the sun only became visible for a short time each day, there was an actual rise in temperature with height. These facts showed that near the ground greater superheating was to be expected in cold regions, but with increase in height the superheating probably became greater in the tropics. The point, however, where superheating in the tropics is the greatest was probably only reached at between 20,000 and 30,000 feet. These statements were borne out when R.34 passed over the Newfoundland ice floes on her outward voyage to America. It, therefore, appeared that provision for superheating should always be made whether the ship flew in tropical, temperate, or cold regions, and especially if the ship were likely to fly at any great height. The point to emphasise in outer covers for tropical regions was the ability to withstand very high temperatures. Mr. Cole's statement that the requirements for the dope in rigid outer covers was essentially different from those in aeroplanes appeared in the past to be true. Recently, however, this divergence had greatly decreased, and there was reason to believe that successful outer covers could be produced using purely aeroplane dopes. It was supposed, in early days, that the contraction produced by dope must, in the case of the rigid outer covers, be small compared with the contraction produced in aeroplane dopes. This had now been proved to be erroneous, and the limiting factor for rigid outer covers was not the strength of the hull structure under compression but the strength of the fabric. In this respect, therefore, the aeroplane and airship requirements were identical. With regard to the last paragraph of the Paper, it was felt that the case of aluminium outer covers was not shown in as favourable a light as was warranted. In large rigids a much larger amount of weight could be allowed for outer covers. An aluminium outer cover could therefore be made of appreciable thickness. The cross section of the ship would presumably be circular, or possibly pear-shaped, instead of polygonal as at present. The change in cross section from polygonal to circular would decrease the head resistance. As there was every reason to believe that future rigids would have less fine lines, probably with a length/diameter ratio of from 5 to 6, the ratio external surface/volume would become less, which would again make for economy in weight of outer cover. In ships of 5 million cubic feet capacity 10 tons could easily be applied to an outer cover of this nature, and great advantages would be obtained, such as long life of gasbags, general ruggedness of the ship, immunity from troubles due to passing through rain, hail, etc., and greater safety in the case of meeting highly charged clouds, and electrical disturbances in general.

Mr. E. H. LEWITT said in reference to hull structure, Mr. Cole, by applying the Bernoulli-Euler simple bending formula, assumed the ship to behave as a solid beam and bend about a neutral axis. This bending formula might only be applied to a built-up tube, such as the hull of a rigid airship, if the three following conditions are fulfilled:—(1) The cross section of the ship must be inscribable in a circle; (2) the sides of the transverse frame must be of equal length; and (3) there must be no variation in the gauge of the diagonal wiring throughout any one bay. Any departure from these conditions would affect the bending stresses in the longitudinal girders. The application of the ordinary simple bending formula to the present type of ship would give considerable errors. The distribution of gas pressure assumed by Mr. Cole would appear to be rather approximate. This pressure acted directly on the gasbag wires, causing them to bulge outwards; it was the components of the tensions in those wires which were taken by the longitudinal girders, the amount of the component depending on the angle of bulge of the wires, and on the type of wiring used. In practice, the radial force on the longitudinal girder was a maximum at the lower part of the ship and zero at the sides, acting outwards at the top portion of the ship and inwards at the base. Mr. Cole stated that there was practically no end thrust on the intermediate longitudinal girders, and yet, by using the ordinary bending formula, he assumed the stresses in the longitudinal members to be directly proportional to their distance from the neutral axis, in which case the bending of the ship would strain the intermediate longitudinals as well as the main. Either the ship did not bend about a neutral axis or the intermediate longitudinals were subjected to the same bending stresses as the main longitudinals. If the latter were the case there was no point in calling them intermediate longitudinals, they were all mains, and should be designed as such. With regard to the king-post and truss, if they were introduced to take the lateral load caused by the intermediate longitudinal girder, in the upper part of the ship where this lateral load was acting outwards, the whole truss might be replaced by two simple girders and an additional radial wire. In the lower part of the ship, where the lateral load was inwards, wires might be substituted for the truss girders. If the reason given by Mr. Cole for the introduction of the truss were correct, it was surprising that the British should copy it, as the difficulty could have been easily overcome by doubling the number of girders in the transverse frame. In his opinion, the truss was adopted by the Germans for strengthening the transverse girder to enable it to withstand the large compression due to a deflated gasbag. Mr. Cole was inconsistent with regard to the rigidity of the joints. In dealing with the diagonal wires, he assumed that the wires took all the shear, thereby neglecting the rigidity of the joints, but in the case of the longitudinal girders, he assumed the joints to be absolutely rigid by applying the generalised equation of three moments. The type of channel used in the girders was inefficient owing to its liability to fail by the buckling of the lips. A much stronger girder could be obtained by using a closed section, such as a tube in place of the channels. Girders whose l/k was below 50 became very inefficient, as they all failed secondarily at the same stress per square inch, due to the unsupported length between the bracings.

Mr. J. R. PANNELL said the second column of the Author's Table I. gave the length of head in terms of diameter for various ships. The head of R.23 was too short, and it had a high resistance; but the head of R.31, which was evolved by means of experiments on models, though only 1.8 diameters long was not markedly worse than that of R.33, which was 1.3 times as long. In the former head the increased bluffness was confined to the region of the nose and the curves were identical over the greater part of their length. The outline of the R.33 head was an ellipse.

The next section of the paper dealt with stability, and it might be useful to define stability in a manner which was easily understood in a physical sense. In the most complete conception of the term no aircraft was stable, since it would

fly indifferently on any compass course; but in the sense required for navigation they might regard an aircraft as stable for rectilinear motion in a horizontal plane (lateral stability) if a rudder setting could be found for which the airship would fly on a straight path. Should a disturbance occur the airship would tend to return to motion along a straight path though, since it had not complete stability in the sense referred to above, the new path might not be the same as, or parallel to, the original one. If the airship were unstable it would move on a circular path of such a curvature that the motion was again stable, and would tend to return to a path of the same curvature after a disturbance.

By the use of this simple theorem it was possible to make a qualitative comparison (it might ultimately prove possible to make an approximate quantitative comparison) between the lateral stability of different unstable ships in the following manner :—The minimum curvature of path for any rudder setting having been determined for the ships, the diameter of the equivalent turning circle was determined. If the ships were not similar and were of different lengths this diameter was divided by the length, and a quantity which he had called the maximum turning coefficient was obtained. This maximum turning coefficient would, of course, be infinite for a stable ship, and its value would be smaller the greater the instability of the airship. The value of the maximum turning coefficient might vary with speed, indeed some evidence of such an effect had already been obtained, but it required confirmation before it could be accepted.

Stability of an airship for flight in a vertical plane (longitudinal stability) could not be dealt with in such a simple manner. The problem was complicated by the rising and falling of the airship, and experiments were rendered difficult by constant changes in trim and in angle of pitch due to the ship becoming heavy or light. An airship was inherently more stable in a vertical plane than in a horizontal one, by virtue of the centre of gravity being situated below the centre of buoyancy; but ease in controlling the height was so important that the horizontal fins and control surfaces were always as large, and generally larger than the vertical ones. It was important in discussing stability to distinguish that quality clearly from controllability; an airship might or might not be controllable, quite regardless of the degree of stability it possessed, unless that degree was very low. However stable an airship might be, it could be made controllable by using sufficiently large controlling surfaces, and an unstable ship might be controlled by sufficiently close attention, if the power of the control surfaces were adequate.

The AUTHOR, replying briefly to the discussion, thanked the Chairman for his kind remarks, and said R.33 formed the basis of their knowledge of modern airship construction and he was sure the Chairman associated the draughtsmen (who were there) with the words he had spoken in regard to the conversion of the knowledge into design. So far as he knew, there were no structural limits of the size of airships. The only difficulty was getting them into the sheds. The swivelling propellers were done away with because of the weight. In the bigger ships manœuvring into position was done at a much greater distance above the ground, and the ship was hauled down by means of lines and a landing party. Regulating the lift near the ground by means of the propellers could not be done by the larger ships. Mr. Campbell said his (the Author's) conclusions were not those used at the Air Ministry, but they formed the basis nevertheless of those used at the Air Ministry. The formula for the tension of the diagonal wires was only for the simple panel system. In a more complicated system where the wires extended over two panels, he believed a modification of the formula he had taken was still used. Mr. May said he had not included the stress in the diagonal wires due to the gasbag pressure. They tried to get the diagonal wires away from the gasbag pressure, so as not to have any stress in them due to this cause. In R.29 the gasbag pressed on the wires and their calculations showed that the stress due to the gas pressure alone was in some cases much greater than the tensions due to the shearing forces. In R.33, the gasbags were kept away from

the diagonal wires by bracing wires and nets. Therefore he did not quite see Mr. May's point in raising that. With regard to the points raised about the assumptions used, a portion of the paper which he had not read dealt with the factors of safety. It was a question of what assumptions one made and what factor of safety was allowed. He admitted that taking the whole of the gasbag pressure in the longitudinals was an extreme assumption, but if one assumes that, and took a low factor of safety, one was in the same boat as a man who went to a much deeper calculation and took a bigger factor of safety. Mr. May said the main longitudinals in R.33 failed at 130lb. per foot. Those figures he thought were for free-ended loading. (Mr. MAY: The figures I gave were for the pressures on the longitudinals due to gasbag pressures and had no connection with the failing strength of the longitudinals.) (The Chairman here intimated that a discussion on this point might be deferred until the written contribution, owing to the lateness of the hour.) In the R.29 they came to the conclusion that the loads on the longitudinals were more than they could safely stand when treated as free-ended beams, yet the ship stood up to the load, and she flew for about a couple of years. With regard to the moment by the stern, if an exact calculation and an exactly balanced ship could be got, everybody would like that, but when Mr. May had had more experience with actual ships he would find they came out worse than the calculation and that a trim by the stern was preferable, so as to avoid the possibility of accidentally trimming by the bow. Referring to Mr. Mitchell's remarks, all the results given in the Lecture were comparative and not absolute results. He held no brief for kingposts and trusses on the transverse frames, but was absolutely against them. He would reply to other points in the Journal of the Society.

Mr. Cole's reply to further points raised is as follows:—

Mr. Johns and several speakers have raised the question of fitting kingposts and trusses to the girders on the main transverse frames. These were first noticed in the German ship L.31, and were retained in all Zeppelin ships up to the time of L.73, just before the Armistice. The reason for their adoption could hardly be that of strengthening the girder in compression, as although there is a certain gain in strength, this could be obtained with a much lower weight by simply increasing the scantlings of the girders. The reason put forward by the Author, namely, that they were to take the lateral load of the intermediate longitudinals, is considered the most reasonable, and on this basis, Mr. Mitchell's suggestion to take the load by means of a radial wire certainly commends itself. The purely kingpost and truss construction has been abolished in later British airships.

The calculation of the stresses in a transverse frame in which the joints are rigid—a point raised by Mr. Johns—is one of great complexity, and it is doubtful whether it could be done with great accuracy. The bending moment and shearing forces on the frame have been considered by Bruhn's well-known analysis, but the results were not convincing.

With regard to the points raised generally by Mr. Campbell and Mr. May, it was realised that it would not be possible to deal within the confines of a single paper with the more intricate problems of rigid airship construction, and it was therefore decided to consider only the simple cases mentioned, rather than to confuse the issue by dealing with the adaptation of these principles to more current airship practice. It is hoped that future contributions to the Society will amplify the more simple illustrations contained therein.

There are, however, several points in Mr. May's remarks which require further consideration. His statement that it was impossible to obtain a hogging moment over the whole length of the ship on account of the full lines of the bow, is certainly not borne out by the fact in the R.33 and R.35 classes, as these ships in all static conditions had everywhere a hogging moment.

The question of stability criteria and fin factors has always been a debatable

one, and several arbitrary factors have from time to time been proposed. For instance, Crocco uses the factor Fin area × distance of centre of area from C.G. of ship/total volume. This factor, however, as with that proposed by Mr. May, is difficult to use in the initial stages of a design, and the form adopted by the Author has been found to be of material assistance in determining a suitable area to start with, as it only brings in the two dimensions of volume and length. It is based further on the theoretical investigation.

Mr. Pannell's remarks on stability and controllability in this connection form a useful addition to this little known subject, and his definitions of stability are of the greatest value. It is hoped that his experiments on R.33 and other ships may soon be published and contribute to our knowledge of the subject.

Commander Land refers to the vexed question of factors of safety. With this is closely allied the question as to how far results are qualitative, and how far quantitative. The method adopted in the early stages of design in this country was qualitative, owing rather to force of circumstances. The calculations were necessarily based on successful ships, and the factors of safety were deduced compatible with the assumptions made. As research and investigation develop, and more data becomes available, the factors of safety will be merged into "factors of science," but until that ideal is reached, factors of safety are necessarily matters for the individual designer.

Mr. Mitchell and Mr. May both mention the strut formula given in the paper. This is of course a well-known form, from which the approximations of Perry, Southwell and Alexander are all deduced. The reason for particularly drawing attention to it is the value of the equivalent eccentricity, and the relation between the crippling load, the span of the bracing pieces and the strength of the channel. The method of application of this formula can be found in any advanced textbook on applied mechanics, in Robertson's reports on the strength of tubular struts, or in the Handbook of Strength Calculations by Pippard and Pritchard.

Mr. Lewitt also mentioned that a more efficient girder could be obtained by using a closed section such as a tube in place of the channel, but such a girder is extremely difficult to construct. Major Crocco proposed a similar idea several years ago in the Italian G design, but this ship was not built. In R.31 and R.32, the closed section idea was adopted, since the wooden bracing pieces or webs could be stuck to the wooden sections, but constructional difficulties have so far prevented its use in duralumin.

Major Pritchard's contribution on superheating is invaluable and interesting. He quotes a number of phenomena based on his extensive flying experiences, which, though at first sight inconsistent, are nevertheless capable of explanation. The protection of the fabric against tendering in the tropics is of course one of the determining factors in the choice of a colour for dope. The whole question of dope for rigid airship outer covers is, however, still in the experimental stage, and it is possible that our ideas on this subject may soon be considerably modified. I am afraid, however, that I am not in entire agreement with him on the question of aluminium outer covers. An aluminium outer cover weighing, say, 150 grams per square metre (which is heavier than present day outer covers) would only be just over 1/20mm. thick, which is of course too thin for practical purposes.

Mr. Lewitt has stated some conditions which must be fulfilled before the simple bending moment equation can be applied to a built-up tube. These conditions are apparently based on wrong premises, as judging from practical results, the application of the simple formula does not appear to give considerable errors.

The fitting of gasbag wires running circumferentially round the ship, or of gasbag bracing wires ending on the joints of the transverse girders, does relieve the lateral loads on the longitudinals to a certain extent. Mr. May is in error in assuming that the intermediate longitudinals should be neglected in calculating the lateral loading. Admittedly the loading on the main B longitudinal with the

intermediates neglected would be 130lb. per foot run, which approximates to the crippling load for a length of the girder equal to the span of the transverse frames and free ends, but the presence of the intermediate reduces this enormously, and in no condition should they be neglected in calculating the lateral load.

The effect of the diagonal wiring is a trifle complex, since it is fitted in panels with rigid joints. Its influence on the change in the tension or compression of longitudinals will, however, be found to be small—certainly not more than 7 per cent.—and the error in neglecting it is on the right side. The design should never be such that the gasbags press on the diagonal wires, and the tension due to this cause should be nil. The case mentioned by Mr. May of a ship having two intermediate frames will be found on investigation to be a simple extension of the shearing force analysis

With regard to Major Smith's remarks, several alternative designs to the Zeppelin have been considered and carefully investigated. The result was, as stated in the paper, to prove that the Zeppelin type was the most efficient.

With regard to the question of substitution of steel for duralumin, it is considered that the future development of rigid airships will be closely bound up with finance, and the design which will, for the same disposable lift and cost of running, be the cheapest to build will be the one to be adopted. Consequently the line of future research work should be rather along the direction of cheaper first cost, and for that reason it is considered that steel will ultimately displace duralumin as the structural material.

I am sorry that no mention was made by any of the subsequent speakers of General Brooke Popham's request for opinions on the use of helium in commercial airships. Although helium is non-inflammable, there is little reason for supposing that it will displace hydrogen as the lifting gas, as it is very much more expensive, there is a loss in disposable lift, and it is doubtful whether for commercial work the "inflammability" of hydrogen is such a dangerous quality as is popularly feared. There are very few cases in which hydrogen has caught fire except by warlike acts—a much more frequent and dangerous cause is from petrol fumes.

The CHAIRMAN, in moving a vote of thanks to the Lecturer, said that this was the first of a series of lectures arranged by the Council to deal with airship matters. The man who was most sceptical about the importance of aeronautical matters was he who knew practically nothing of them. When anyone received even a reasonable introduction to aeronautical work he usually realised at once the possibilities and the consequent importance for both civil and warlike purposes. The same state of affairs obtained with regard to airship matters. Even in an aeronautical society such as this it was only from those really familiar with airship work that enthusiasm for airships could be expected. It was of vital importance, to this country especially, that airships should be developed for both commercial and warlike purposes, and this series of lectures should be of great value in stirring up interest in airships and their future possibilities. Mr. Cole had given a very interesting lecture on the "Principles of Rigid Airship Construction"; Squadron Leader Pritchard would lecture on February 4th on "Rigid Airships and their Development for both Civil and Service Purposes," and would give interesting details of the state of development at home and abroad, the present requirements and the difficulties experienced in obtaining them. On March 17th, Mr. Abell, who was recently the senior engine officer in the Airship Service, would lecture on "Airship Machinery." It was also probable that a lecture on "Airship Towing, Mooring and Handling" would be given either later in the spring or next autumn. The development of airship construction and operation was extremely difficult with the small amount of money which was now available, because of the size of each unit which had to be constructed to test out a new design. The expense was much greater than in the case of aeroplanes.

To carry 29.5 tons 1,000 miles, which is possible with R.38, some 50 typical large aeroplanes were necessary, but to investigate and improve the design of such a unit one complete ship must be built. In spite of the great industrial difficulty in Germany, rapid progress was even now being made by them in airship development. The capacity of the airship had gone up three times, the disposable lift three times, the weight of the hull from 16 to 20 tons, and the speed from 43.5 miles to 72 miles an hour. We had to expend a large sum of money and research to keep pace with it. The "Bodensee," although a very small ship of three-quarters of a million cubic feet capacity, had a ratio of disposable lift to total displacement as high as 45 per cent. and the speed of the ship was over 80 m.p.h. The Americans also realised the importance of rigid airship construction, and in addition to purchasing our latest ship, R.38, were spending an amount of money in making arrangements for research and experimental work which caused British airship officers to be extremely envious. He considered that Mr. Cole had done very good service in preparing and reading this paper, and that the Society was greatly indebted to him.

REVIEWS.

"**Applied Aerodynamics,**" by L. Bairstow, F.R.S., C.B.E. Longmans, Green and Co.

Mr. Bairstow has by his work contributed very largely to the existing knowledge of the subject of Applied Aerodynamics. His papers on the stability of aircraft showed how the theories of Bryan and others could be applied and have led to the present methods of determining stability. The book under review is a worthy addition to Mr. Bairstow's previous work and is a very valuable addition to the literature on this important subject.

In common with much of the previous work referred to this book is perhaps a little too mathematical for the average engineer, who has, through pressure of other work, to let the purely mathematical side of his training fall into disuse, but to the student and the engineer engaged upon research this book will prove to be of the greatest value.

The Advisory Committee for Aeronautics has published from time to time a number of reports upon research work carried out at the National Physical Laboratory and the Royal Aircraft Establishment. These reports are of necessity very concise statements of results obtained with very little explanation of methods used or interpretation of results. Mr. Bairstow's book gives a clear indication of the methods to be employed in applying the results as given in these reports to practical problems and forms a general guide to their intelligent use.

If the book is now considered in detail, it is noticed at once that many problems connected with the "lighter than air" type of aircraft are included. This forms a new feature, as previous works have usually dealt solely with the "heavier than air" type.

The principles of flight are carefully explained in Chapter II., and the latest methods of setting out the curves to give revolutions of the airscrew under different conditions of flight are given, including the case when an aeroplane is nose-diving and the airscrew is acting as a windmill.

When considering the effect of tail planes of different size the author leads up to the conclusion that with a certain position of the centre of gravity of the aeroplane the control may not be sufficient to stall the aeroplane, which condition tends to safety in flight. This conclusion would appear to require some qualification, for under these conditions it is probable that the control would also be insufficient for flattening out when landing.

The description of the methods of measurement employed on model and full scale experiments, given in Chapter III., covers all the usual methods of test and is of particular assistance in understanding the result as given in Advisory Committee reports.

Chapter IV. deals with the design data from aerodynamic laboratories and explains the various coefficients in general use and the methods adopted for plotting out the results obtained. Some typical results are given, but these are merely to explain their use, and the original reports should be consulted if any actual values are required. For instance, the original reports deal with many different aerofoils, whereas Mr. Bairstow has only given a few typical examples. The paragraphs dealing with the body resistance as affected by the airscrew and the analysis of the resistance of a complete model, as compared with its component parts, should be closely studied as a clean aeroplane can only be designed by attention to points such as are raised in these paragraphs.

By the use of recording accelerometers and other instruments the forces acting on an aeroplane during aerial manœuvres have been measured and recorded.

In Chapter V. these results are analysed and comparison made with the results obtained by calculation for similar manœuvres. The method of making these calculations is given and the particular case of a loop is considered in detail.

The chapter devoted to airscrews is of particular interest in view of the various theories which have been adopted at different times, but more particularly as future development would appear to require that the variable pitch or variable surface airscrew must be produced to meet the requirements of high flying and of probable engine development. With these requirements in view the airscrew can be made to yield real improvements in aircraft. Mr. Bairstow gives the mathematical theory, using the usual combination of the Froude and Drziwiecki theories, and then by comparison with test results deduces average values for the various factors used. The results indicate that no exact theory can be developed and that the design of an airscrew for a particular machine must for the present be done by a system of intelligent guessing, due to the effect of the body on the airscrew, but the experiments conducted in order to find these effects are dealt with in detail.

The difficulties of the subject are indicated in Chapter VII., dealing with fluid motion, where it is shown to what a very limited extent the present mathematical theory of fluid motion can be used in connection with the problems presented.

Chapter VIII. explains the now accepted theory of dynamical similarity and gives the scale effects as affecting the application of model results to full scale as far as these are known at present. There is still plenty of scope for research in this direction.

During the war a great advance in the theory of aerodynamics was made by the development of a method of prediction and analysis of aeroplane performance. This method is explained in detail in Chapter IX., and some interesting curves are given for the rapid prediction of the performance of aeroplanes. Probably the most important part of the whole book is in the method of analysis of performance; this has enabled the results obtained from test flights to be so analysed that fairly accurate estimates of the actual thrust, etc., can be obtained. Advance in any direction can only be made if the various factors entering into the problems can be accurately separated, and this method of analysis has enabled the good and bad factors to be separated with consequent advances. This method has of necessity many approximations, but when once a method of this kind has come into general use these approximations will soon be reduced by a step by step process.

The last chapter deals with the mathematical theory of stability and covers most of the work previously done by Messrs. Bairstow and Naylor, which has been given in Advisory Committee reports. This chapter requires very close study in order that the results can be appreciated, and for this reason it would be of decided advantage to the designer if Mr. Bairstow could reduce his results to some straightforward working rules which could be followed in setting out the various surfaces of aircraft.

E. W. S.

CORRESPONDENCE.

To the Editor THE AËRONAUTICAL JOURNAL.

DEAR SIR,—May I be allowed to correct an apparent misapprehension on the part of your reviewer of my "Handbook of Modern Aeronautics."

In common, and in apparent parallel with one or two almost identical reviews, since fortunately corrected in subsequent issues, the article in question ignores the fact that there existed a very rigorous Technical Press Censor, and that owing to the exigencies of the printing trade, there has been an abnormal delay in publication of such works as the one in question.

In the present case, this work was actually in type in October, 1918, a year or so after it had left my hands! But owing to the above circumstances, it was not published until August, 1919. There was therefore no rush for publication. Having had full access to official technical records and data whilst in the Air Ministry, I am, of course, well aware of the omissions in one or two of the nineteen odd sections affected, but even now, there is little official information allowed to be made public, and rather than risk a further indefinite delay, it was decided to proceed with publication as early as possible.

The excellent reception, and sales of this work have fully justified this decision, although it is realised that the data in one or two sections is not so complete as one would have wished. This will of course be rectified and the matter extended in subsequent editions, at the appropriate time.

I should feel obliged, Sir, if you would kindly give this letter the same prominence as the review in question.

Yours faithfully,

ARTHUR W. JUDGE.